A Procedure for Increasing the Accuracy of Surface Current Charts Based on Hydrodynamic Observations

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(*Received for publication December 23, 1936*)

ABSTRACT

The surface densities of the sea are observed at small intervals while proceeding between stations of a hydrodynamic survey. The movement of the surface waters may be calculated separately in detail and superimposed on the deep currents as observed, permitting the preparation of surface current charts on a much larger scale than is normally permissible.

In hydrodynamic current surveys based on Bjerknes' theorem in coast areas, it is customary to observe the density of the column of water at each of a series of several stations in a line approximately at right angles to the general coast-line in the area under investigation. The stations are usually spaced from five to ten miles (9 to 18 kilometres) apart in the waters adjacent to the coast and at increasing intervals as the deep sea is approached.

It is generally presumed that the density gradient can be accurately determined from precise observations at such stations, although it is known that in coast waters there are variations in the surface densities that tend to offset this, and the present investigation shows the influence of some of these surface variations on hydrodynamic calculations.

In the course of hydrographic surveying with recording sonic sounders off the Pacific coast of Canada, the ship steams at full speed (12 knots) along a course at right angles to the coast and returns landward along a parallel course one mile (1.8 kilometres) distant. The position of the ship is fixed by three point bearings every four minutes of time and recorded.

During this procedure in 1934, the opportunity was provided on four different occasions for collecting surface sea water samples in a bucket cast over the side each time the ship's position was fixed. On June 8 the temperature of every sample and the chlorinity of every fifth sample were determined, on July 6 the temperature and chlorinity of every sample were determined, and on July 18 and 24 the temperature only was recorded.

Figure 1 is a chart of a section of Vancouver island showing the location of the four areas investigated, the isometers of temperature (isotherms) at intervals of 0.2°C., the points at which the observations were made, the tide curves during the period of the observation, the direction of the tide stream, and the direction and force of the wind.

Table I shows the rate of variation of the temperature in degrees centigrade per mile (1.8 kilometres), and the range, in each area in directions parallel and at right angles to the wind.

The observations of areas A, B and C were made during the periods of strong westerly winds which usually varied from force 2 (Beaufort) in the morning to force 5 or 6 about an hour before sundown, when they generally fell to force 2 and continued so throughout the night. There was practically no rain during these

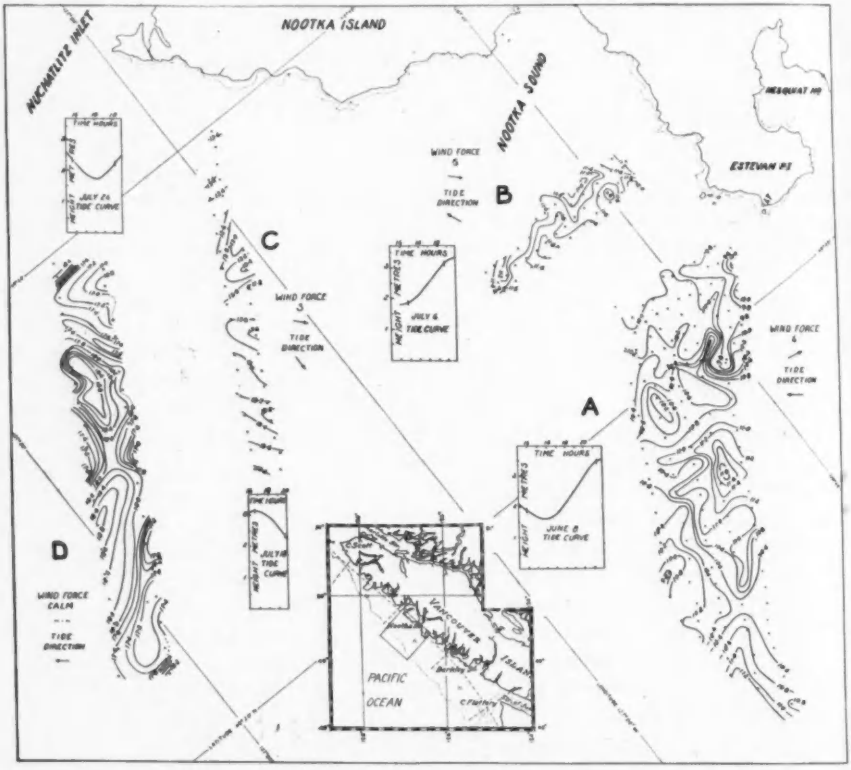


FIGURE 1. The four areas investigated, showing surface isotherms and associated data.

periods and the surface waters had an excellent opportunity to become thoroughly mixed. Area D was observed during a period of unusual flat calm weather.

In areas A and B the temperature changed more rapidly in a direction parallel to the wind than across it, which is fully explained by the illustrations of Sandström (1919).

Temperature changes are not considered across the areas C and D since there are only two lines of stations in each of these and it is considered necessary to have more than two observations in line to determine the rate of change of temperature.

TABLE I

Area	A	B	C	D
Wind force	4	6	3	0
Tide	Flood	Flood	Ebb	Low water
Temperature (°C.) variation per mile (1.8 kilometres)				
Parallel to wind	0.55	0.50	....	....
Across the wind	0.32	0.35	0.31	0.47
Range of temperature (°C.)				
Parallel to wind	2.0	0.8	...	...
Across the wind	1.6	0.8	1.0	1.8

The rate of temperature variation in area D is much greater than in any area which was observed during windy weather. The rate of change of temperature with distance and the total range in small areas such as these are much less during a period of winds than in calm weather, since there is a greater mixing of the surface waters.

The isometers of density (σ_t) are shown in figure 2 and the data are analyzed in table II similar to the temperature in table I.

TABLE II

Area	A	B
Wind force	4	6
Tide	Flood	Flood
Density variation (σ_t) per mile (1.8 kilometres)		
Parallel to wind	0.07	0.11
Across the wind	0.05	0.07
Range of density (σ_t)		
Parallel to wind	0.25	0.26
Across the wind	0.35	0.32

There are few illustrations of the isometers of temperature and density in the literature of hydrodynamics where the observations are less than five miles (9 kilometeres) apart, and the most are from five to ten miles (9 to 18 kilometres) or more apart in coast areas. The data shown in the figures demonstrate that the temperature and chlorinity variations may have significant effects on the density in distances as small as half a mile (1 kilometre).

The surface currents in the ocean are particularly susceptible to the wind and in areas A and B, which were observed after periods of fresh winds and were probably as nearly homogeneous as they ever become during the summer, the range of variation in density (table III) is certainly significant and these extremes of range may be found within a distance of three miles (5 kilometres) or less.

The current induced by the winds is a resultant of the average force and direction of the wind over the period required to induce the current, and once

such a current is set up there is a definite moment of inertia acting against any change in velocity or direction. Consequently the current lags behind the changes in wind force and direction.

Currents below the surface of the sea are not exposed to the gust effects of the wind and, in addition to the inertia to change, they are liable to friction with both the over and underlying water mass and consequently are much steadier than the surface currents.

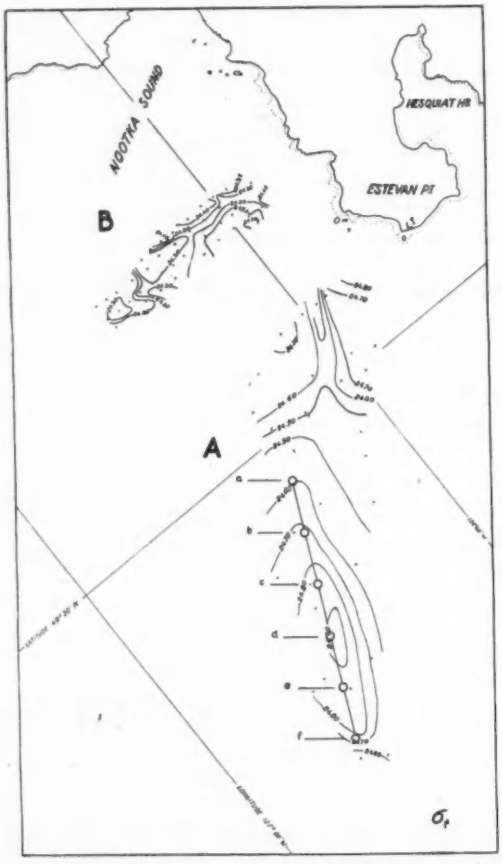


FIGURE 2. Areas A and B, showing surface isosteres.

From this it is evident that the gradient of the current would be more regular at some small depth, ten metres for example, than at the surface, and would more nearly represent the average current across a dynamic section than those observed at the surface.

However, the knowledge of the real surface currents is of particular interest to navigators and students of drift, as well as to fisheries researchers, and it is of definite value to show the surface currents in as much detail as possible.

TABLE III

Column....	1	2	3	4	5
Station	σ_t Surface	σ_t 10 metres	Dynamic height 10 metres to surface	Dynamic height 800 metres to 10 metres	Dynamic height 800 metres to surface
a	24.60	24.93	9.7581	767.9577	777.7158
b	24.72	24.90	9.7577	767.9573	777.7150
c	24.81	24.87	9.7574	767.9569	777.7143
d	24.90	24.84	9.7570	767.9565	777.7135
e	24.83	24.81	9.7576	767.9561	777.7137
f	24.72	24.78	9.7583	767.9557	777.7140

If the currents at ten metres depth are determined and charted from dynamic observations, the minor variations at the surface may be shown from intermediate surface observations by calculating the dynamic height of the surface from the dynamic height (or interpolated dynamic height between stations) of the ten-metre isobaric level.

Since the gradient at ten metres is more regular than that at the surface, and in any case must be assumed to be regular, the average density of the water between the surface and ten metres depth may be calculated in the usual manner from the observed surface density (σ_t) and the interpolated density at ten metres.

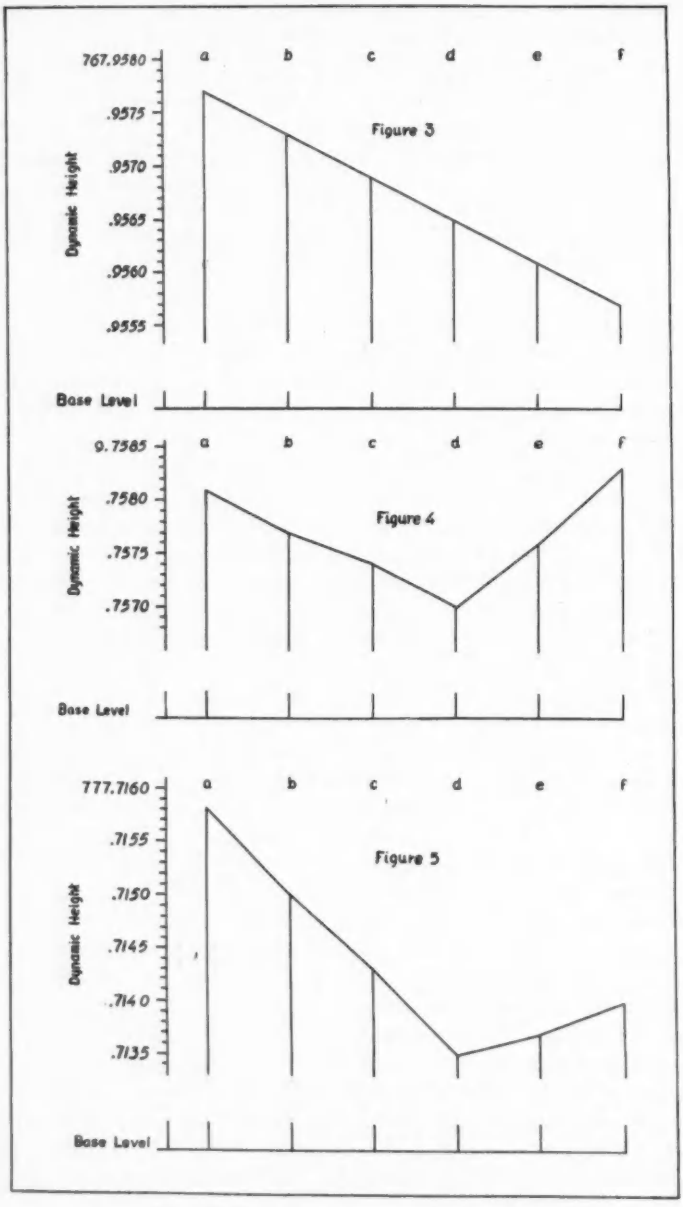
In a simple instance, the dynamic heights of columns of water at the stations marked *a* and *f* (figure 2) were observed from a base level of eight hundred metres depth. The stations were 4.90 miles (9.08 kilometres) apart. The dynamic height of the surface at station *a* was 777.7158 dynamic metres and at *b* was 777.7140, indicating a gradient current of 0.004 knots (0.2. cms./sec.) northwestward across the section. Figure 3 illustrates the dynamic gradient of the ten-metre isobaric level from 767.9577 dynamic metres at station *a* to 767.9557 at station *f*, and indicates a current in the same direction as the surface with a velocity of 0.004 knots (0.2 cms./sec.).

However, four intermediate surface observations were made at positions *b*, *c*, *d* and *e*, at intervals of 0.98 miles (1.81 kilometres), and treated as dynamic stations with a base level at ten metres depth.

The observed surface σ_t are shown in table III, column 1, and the observed σ_t at ten metres depth at stations *a* and *f* and interpolated σ_t at ten metres depth at *b*, *c*, *d* and *e*, are shown in column 2. The calculated dynamic height of the surface above the ten-metre isobaric level is shown in column 3 and graphically illustrated in figure 4. These dynamic heights may then be superimposed on the gradient shown in figure 3, resulting in the dynamic section shown in figure 5.

The superposition may be accomplished by interpolating the dynamic heights of the ten-metre isobaric level for positions *b*, *c*, *d* and *e*, from the heights at stations *a* and *f*, as shown in table III, column 4, and illustrated in figure 3, and adding this value to that in column 3. The resulting dynamic height of the surface above the eight hundred-metre level is shown in column 5.

From this it can be shown that there is a gradient current of 0.08 knots (4.0 cms./sec.) between *a* and *b*, 0.07 knots (3.5 cms./sec.) between *b* and *c*, and



Dynamic sections from station a to station f.
FIGURE 3: between 10 and 100 metres. FIGURE 4: between surface and 10 metres.
FIGURE 5: between surface and 800 metres.

0.08 knots (4.0 cms./sec.) between *c* and *d*, northwestward across the section. At *d* the direction changes and the velocity between *d* and *e* is 0.02 knots (1.0 cms./sec.) and between *e* and *f* is 0.03 knots (1.5 cms./sec.) southeastward.

The surface detail is particularly important in the study of coastwise circulation where it greatly aids the interpretation of eddy currents. If no surface observations have been made in this section, some of the important features of surface circulation would have been overlooked.

Citing the section from station *a* to *f* (figure 2) as an example, the regular intermediate surface observations permit the calculation of surface velocities in detail from a base about ten metres depth. These when superimposed on the more regular deep currents found, permit the preparation of current charts on as large a scale as the accuracy of observation of position will permit, which is much larger than is normally permissible.

These surface calculated currents based on interpolations on the ten-metre isobaric level are not absolute, and a much more accurate chart could be made by observing complete dynamic stations at the intervals of these surface observations. But this method of charting surface detail is a closer approach to the true surface currents than that obtained from the regular dynamic observations, and moreover, the observation of complete vertical columns at intervals of less than five miles (9 kilometres) is unduly tedious and expensive. Therefore it is suggested that in dynamic surveys, the surface densities be observed at intervals of approximately one mile (2 kilometres) while the ship is proceeding between stations, and that the position be fixed at each observation. The variations of the currents in the surface layer can then be superimposed on the deep currents found. This procedure has the advantage of increasing the normal accuracy with a minimum of time and expense.

SUMMARY

The rate of variation of the surface water temperatures in four small areas off the west coast of Vancouver island during different wind conditions has been shown.

The rate of variation of surface densities has been shown in two of these areas and the effects on hydrodynamic calculations based on the usual observations indicated.

A procedure for increasing the accuracy of surface current charts based on hydrodynamic observations has been suggested.

ACKNOWLEDGEMENT

These observations were made through the courtesy of the Canadian Hydrographic Service and particularly Mr. H. D. Parizeau, Hydrographer on the Pacific coast of Canada, who made the services of the ship, the "William J. Stewart", available.

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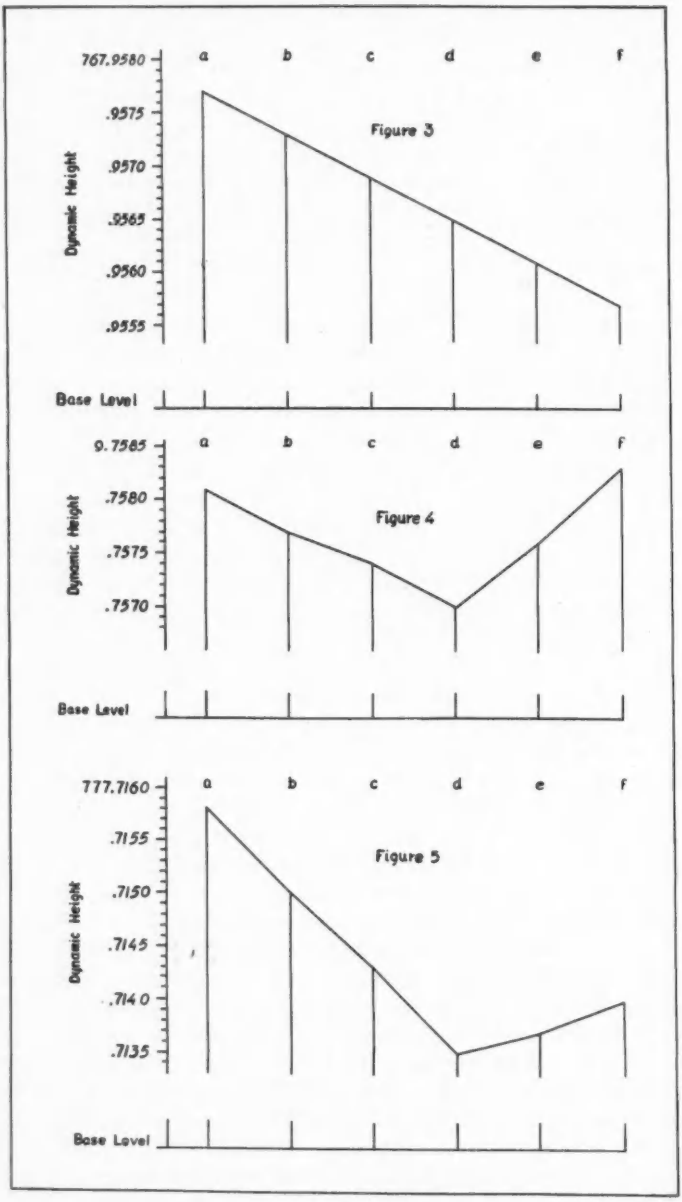

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The Application of Thermal Data to the Calculation of Sterilizing Times for Canned Fish

By D. LeB. Cooper
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(*Received for publication January 4, 1937*)

ABSTRACT

It is shown experimentally that the equation for heat flow in a finite cylinder

$$t = \frac{2.302}{K} \frac{1}{\left(\frac{2.40}{a}\right)^2 + \frac{\pi^2}{4l^2}} \log 6.42 \frac{(T_r - T_o)}{\pi(T_r - T)}$$

can be effectively used with lethality data for the controlling organism to calculate sterilization times for fisheries products packed solidly into cylindrical cans.

The sterilization of canned fish is a function of two variables (1) the rate of heat penetration into the tin, and (2) the thermal death rate of the contaminating organisms. This communication is concerned with the first, namely, the rate of heat penetration into cans of solidly packed fisheries products treated in the steam bath.

The primary object of the investigation was to determine the degree to which one may rely, in practice, on heat penetration data calculated from the equation for the flow of heat in a finite cylinder, using an experimentally determined mean value for the diffusivity, K. Some data of the heat lethality of certain organisms are used to demonstrate the effects of changes in certain factors on the processing times.

As a first approximation the equation for heat flow in a finite cylinder of radius a and length $2l$ is

$$t = \frac{2.302}{K} \frac{1}{\left(\frac{2.40}{a}\right)^2 + \frac{\pi^2}{4l^2}} \log 6.42 \frac{(T_r - T_o)}{\pi\ (T_r - T)}$$

where 't' represents the time in seconds for the centre of the can, originally at a temperature of T°C. to reach a temperature of T_o°C. with a retort temperature of T_r°C. K is the diffusivity in C.G.S. units. (Langstroth 1931).

Whether or not the sterilization times may be estimated by the aid of this equation depends primarily not on the constancy of the value of K for various solidly packed products placed in cylindrical tins of varying shapes, but on the

degree to which the bacterial death rate is affected by time-temperature relations brought about by variations in K.

EXPERIMENTAL METHOD

The method consists in measurements of the rate of heat penetration into various products under different sets of conditions, and calculation of K by substitution in the equation that has been given. The mean values of K were combined with the lethality curve for the organism *B. botulinus* (Weiss 1921) to calculate sterilization times for other sets of conditions. These were then compared with the actual times as calculated from the experimental data on heat penetration.

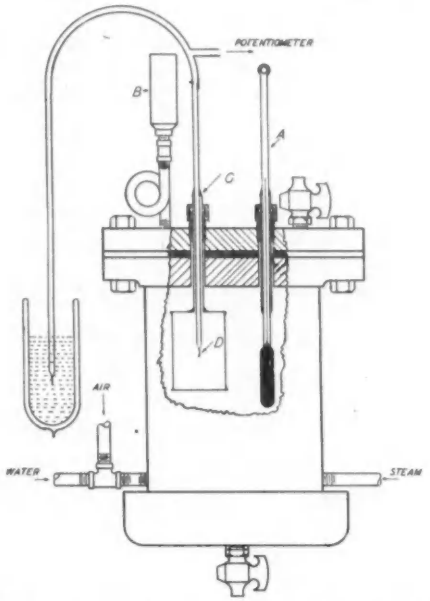

FIGURE 1. Apparatus for heat penetration measurements. A,—retort therm.; B,—press. gauge; C,—copper to glass seal, and stuffing valve; D,—tin showing inserted couple.

The apparatus consisted of a suitably designed steam retort so arranged that a can could be suspended inside. Temperatures in the centre of the can were read by means of protected thermo-couples, the case of which protruded through a stuffing valve and acted as the suspension. The arrangement is shown in figure 1.

The can was maintained at a constant temperature in an external bath for a sufficient length of time to reach a uniform temperature throughout, placed in the retort and the steam admitted. The retort required about 30 seconds to reach full temperature. This lag was disregarded in treating the results.

Time-temperature readings were taken, and from these a direct graph was

made. The upper section of the latter was rectified and data for the calculation of K determined from this.

The results from a typical run are plotted in figure 2.

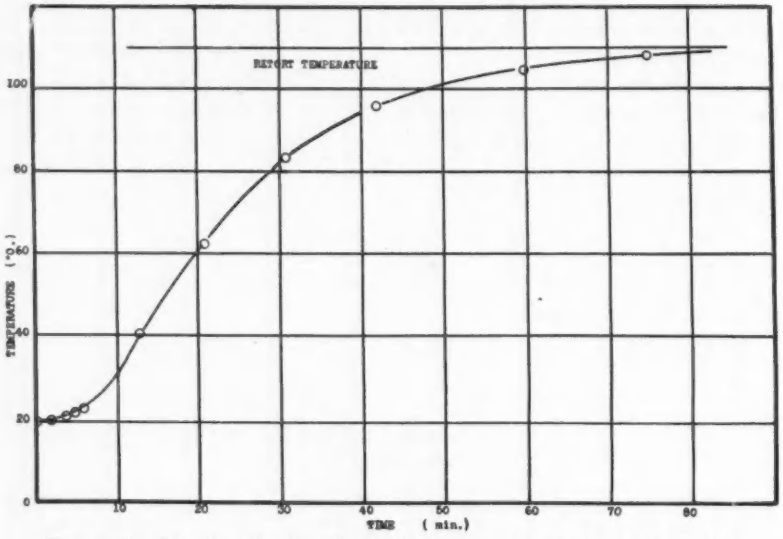

FIGURE 2. Direct graph of results of a typical experiment on heat penetration.

A summary of results is given in table I.

TABLE I. Summary of results on the determination of the value of K for different products packed in no. 1 standard cans

Product and description	Temperatures °C. Initial	Retort	K
Mackerel re-heated commercial pack	25	110	.0016
Mackerel frozen unprocessed	11.2	110	.0014
Mackerel re-heated frozen	..	...	.....
Mackerel re-heated frozen	40	110	.0019
Mackerel re-heated commercial	21	110	.0014
Mackerel as above	21	110	.0015
Mackerel as above	44	110	.0018
Mackerel as above	21	120	.0015
Mackerel as above	44	120	.0020
Tuna paste steamed and dried	24	110	.0014
Cod canned untreated	20	110	.0017
Cod canned steamed	20	110	.0016
Lobster paste fresh from steamed lobster	20	110	.0016
Cod (Langstroth's value from heat penetration data)	..	...	.0016
Cod (Langstroth's value determined by hot-plate)	..	...	.00164

DISCUSSION OF RESULTS

The calculated error in the determination of the value of K in each case (table I) is approximately 15 per cent. For this reason the only significant differ-

ences are between those cases with the initial temperatures from 11.2 to 25°C. and those with initial temperatures of 40 and 44°C.

The results indicate that in so far as the value of K is concerned, differences in the type of solid pack, and in retort temperatures have no significance. The value of K increases as the initial temperature rises.

Changes in the value of K as mentioned above are the first concern, but for

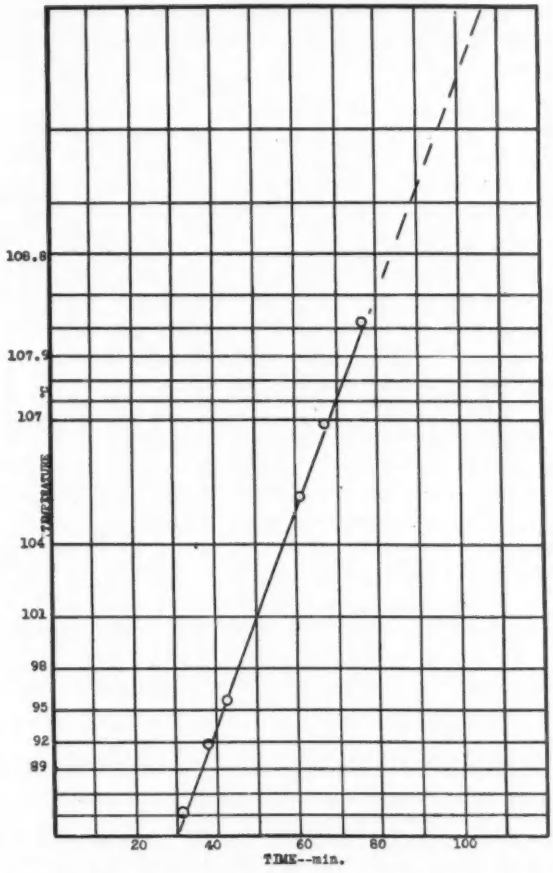

FIGURE 3. Rectified upper portion of a curve for heat penetration.

this purpose not the chief one. The usefulness of the method is limited by the extent of the range in retorting time due to differences in the value of K. The retorting time depends on other factors among which the time-lethality curve of the organism controlling the sterilization is important. The curve (figure 4, left) used in the calculations is thought to be typical. It is for the most resistant type of non-thermophilic organism in approximately the same environment as exists in canned fishery products.

If lethality be defined as the recripocal of the times necessary to kill all of a suspension of a definite organism at different temperatures, lethality and heat penetration data may be combined to calculate sterilization times. Details of the calculation are given by Bigelow (1920). Figure 4 shows (A) the lethality curve for the organism *B. botulinus* referred to the lethality-temperature axes, and (B and C) referred to the time-lethality axes, combinations of the same lethality curve with two different heat penetration curves to give values of 73 and 82 minutes for the sterilization times of a 1-lb. standard tall can retorted at a temperature of 115°C. The value of K was assumed to have changed from 0.0016(C) to 0.0014(B).

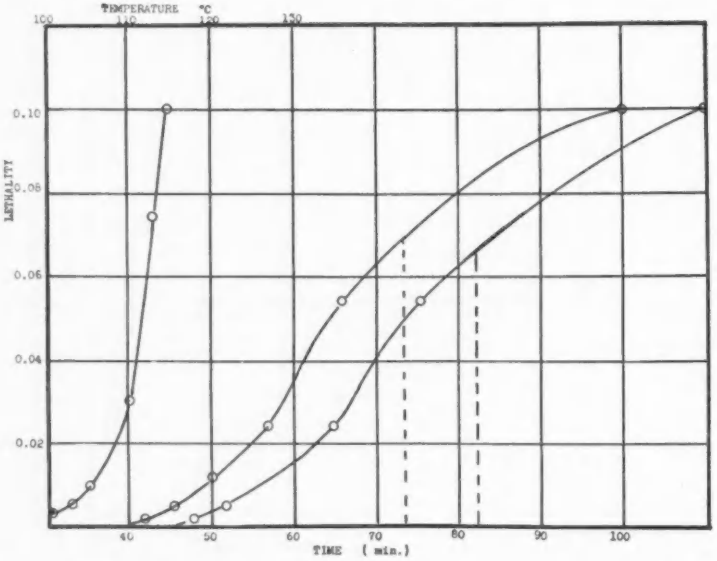

FIGURE 4. Lethality curve of *B. botulinus*, and two curves showing the method of determining the time for sterilization.

Table II shows the results from a similar set of calculations for number 1 standard cans.

TABLE II. Differences in sterilization times with different values for the constant K and with differential retort temperatures. Number 1 standard cans.

Retort temperature °C.	Initial temperature °C.	K c.g.s.	Sterilization time (minutes)
120	20	0.0014	64
		0.0016	64
115	20	0.0014	82
		0.0016	73
110	20	0.0014	112
		0.0016	102

The discrepancies between values calculated from the equation and experimentally determined times for flat cans are given in table III.

TABLE III. Discrepancies between calculated and experimentally determined sterilization times, where K constantly = 0.0016, and the cans differ in the ratio $a/2l$.

Conditions Temperatures		Can designation	Results Ster. times (minutes)		
Retort	Initial		Exp.	Theor.	
115	20	1 lb. flat	66	73	7
115	20	½ lb. flat	58	63	5
115	20	¼ lb. flat	41	43	2

The following considerations show that the differences indicated are not significant.

Solid packs of fish are rarely processed at temperatures below 110°C. This limits the discussion to this value and above. For retorts operating without compressed air it is not feasible to process at temperatures above 120°C. Thus for all practical purposes the discussion is limited to temperatures within this range.

The differences were obtained from the ideal case in which the retort reached its final temperature of 115°C. in about 30 seconds, and cooled instantaneously. In industrial practice a lag of ten or more minutes is not uncommon, and furthermore, the constancy of the temperature or in fact its absolute value are not maintained with precision. Again, bacterial contamination may vary from day to day and from season to season. Furthermore, except under the best of conditions the rate of cooling is not controlled. All these variable factors leave the value of accurate timing in doubt. Therefore it is concluded that the indicated differences are not significant, and the two mean values of K in conjunction with the approximate form of the equation for the penetration of heat into a finite cylinder may be used for the calculation of sterilization times for cans of solidly packed fisheries products.

Finally, it should be emphasized that these conclusions are intended to apply only to those products which are packed without the addition of water or "pickle", and which have not received strong drying treatment. It has been shown experimentally that the addition of pickle raises the value of K to 0.0022 and greater. The limits of dryness have not been determined. Products reduced in moisture to approximately 50 per cent give the same value for K.

The nature of the heat penetration curves are such that in the case of a highly resistant form a change from one temperature of processing to another would appear to be advantageous. This is demonstrated by the following for a can of certain size requiring a process of 120 minutes with a retort temperature constant at 115°C. If the retort be first operated at a temperature of 125°C. for 30 minutes and then reduced to 115 for 60 minutes, i.e., total time of 90 minutes, the contents will be sterile and the temperature of the contents at the centre of the can will not be greater than 115°C. at any time, and the contents of the whole can will be at a temperature of 115°C. at the end of the processing period.

This method is of particular advantage when highly resistant forms of organisms are present. The saving in time on a no. 1 standard can contaminated with a thermophilic organism and retorted as outlined above is 47 minutes. With air pressure retorts, either batch or continuous type, still greater temperature differences are feasible.

For those products adversely affected by prolonged heat treatment there will be a can of certain size and shape which will be best suited to their processing. The dimensions of this can may be determined for any set of retorting conditions, from the following equation:

$$T_r - T = 2.05\,(T_r - T_0)\,J_0\left(\frac{2.40r}{a}\right)\sin\frac{\pi}{2l}(z+l)e^{-\kappa\left[\left(\frac{2.40}{a}\right)^2+\frac{\pi^2}{4l^2}\right]t}$$

(Langstroth private communication)

in which the symbols have the usual significance.

Thus in the case of a can for which $a=4.0$, $l=6.0$, $t=20°C.$, $T=110°C.$, and $K=0.0016$, it will require about 100 minutes for the contents at the centre of this can to reach a temperature of 107°C. The temperature of the contents at a point half-way to the centre ($r=2$, $z=0$) is given by the following figures:

time (minutes).....	20	30	40	50	60
temperature °C.....	69	90	99	104	107

The contents at this point are above 107°C. for a period of 40 minutes and above 99 for a period of 60 minutes before the centre reaches the temperature of 107°C. If the contents deteriorate under prolonged heating then the quality at this point will be adversely affected. If the rate and type of deterioration be known the optimum conditions for the least severe treatment consistent with sterilization at the centre may be calculated.

The rate of cooling of a can affects the time the can must remain in the retort, for if the centre of the can remains hot for some time after removal the effective sterilization time is increased.

The cooling of a can is given by an analysis similar to that of heating. The first approximation equation is (for the centre of the can)

$$\theta - \theta_c = 2.05\ (\theta_0 - \theta_c)e^{-\kappa\left[\left(\frac{2.40}{a}\right)^2+\frac{\pi^2}{4l^2}\right]t}$$

(Langstroth private communication)

where θ_0 is the temperature of the contents when the retort is opened at $t=0$, θ_c is the temperature of cooling and θ is the temperature at the centre at a time t.

With a can retorted as example 1 and cooled in water at a temperature of 20°C. we find

time (minutes).....	20	30	50	70
temperature (centre).....	75	50	29	22.8

i.e., the central portion is above 75°C. for 20 minutes after the retort is shut off. This causes an additional sterilization time which may be allowed for in the calculation of sterilization times where factory conditions are such as to warrant it.

If it be important to minimize such factors as thermal spoilage of the con-

tents, the most suitable combination of method and temperature of retorting, and type and temperature of cooling, can be calculated. Data on thermal spoilage available at present are insufficient to warrant general recommendations.

ACKNOWLEDGMENT

The interest and criticism of G. O. Langstroth has aided greatly in the preparation of the manuscript. The last two suggestions on retorting procedures are his, as are the calculations for them.

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Populations of Herring (*Clupea pallasii*) in the Coastal Waters of British Columbia

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(*Received for publication June 9, 1936*)

ABSTRACT

From an analysis and comparison of various counts and measurements made on herring from different localities along the coast it is concluded that intermingling of the stock as a whole is limited and that there exist a number of essentially discrete units or local populations within the waters of the province. The evidence for this conclusion is based on gradations in mean vertebral and keeled scale counts with latitude and on significant and constant differences between herring of different localities in one or more of the following characters: total vertebral count, abdominal vertebral count, sex ratio, rate of growth, head length and length to the insertion of the dorsal fin. Data on these characters are analyzed as completely as feasible in an attempt to interpret all sources of variation.

INTRODUCTION

The Problem

From a consideration of differences in body structure between samples of fish from the same and from different regions, European investigators have concluded that the Atlantic herring (*Clupea harengus*) consists of a number of different races (Lissner 1934). From similar considerations, Rounsefell (1930) concludes that the Pacific herring (*Clupea pallasii*) is also divided into a series of races or populations extending along the west coast of North America from California to Alaska. He also shows that the herring of Alaska may be further divided into a series of "local populations" extending from south-eastern Alaska to the Aleutian islands. More recently, Rounsefell and Dahlgren (1935) from comparisons of vertebral count and also from the results of tagging experiments have enumerated certain local populations occurring in south-eastern Alaska.

Little is known concerning the herring of British Columbia in this regard. Measurements and counts of "racial" characters made by Thompson (1917) and discussed by Hubbs (1925) and Rounsefell (1930) demonstrate that the herring of southern British Columbia are essentially distinct from those of California to the south and south-eastern Alaska to the north. The present paper deals with an analysis and comparison of measurements and counts made on herring from various localities in British Columbia from 1929-30 to 1934-35 with the primary object of determining whether the total stock may be regarded as one large population, the members of which intermingle freely and undertake extensive migrations along the coast, or whether the total stock consists of a number of essentially discrete units or local populations, each with a limited range of migration.

ACKNOWLEDGMENTS

The investigation has been conducted under the supervision of Dr. W. A. Clemens, Director, and Dr. J. L. Hart, Assistant Biologist, Pacific Biological Station, Nanaimo, B.C. To these, and to Dr. A. G. Huntsman, Professor of Marine Biology, University of Toronto, many thanks are given for the benefits of consultation and for the critical reading of the manuscript. For the latter, the author is also indebted to various members of the staff of the Biological Station and to Dr. G. A. Rounsefell and Mr. E. H. Dahlgren, U.S. Bureau of Fisheries, Seattle, Washington. Thanks are also tendered to Dr. J. L. Hart for contributing measurements, counts and scales of herring collected during 1929-30 and 1933-34, and to Dr. D. C. G. MacKay, formerly of the Pacific Biological Station, for similar material collected during 1930-31.

The investigation has been materially furthered by the co-operation of Major J. A. Motherwell, Chief Supervisor of Fisheries, Mr. J. F. Tait, Supervisor of District No. 3, Mr. J. M. Boyd, Supervisor of District No. 2, and many other officers of the Dominion Department of Fisheries in this province in collecting samples and in supplying information pertaining to the fishery. The author is also indebted to the managers, crews and fishermen of many salteries, reduction and cold storage plants for giving free access to their supply of fish.

Financial assistance from the Provincial Fisheries Department during part of the period of investigation is gratefully acknowledged.

MATERIAL AND METHODS

SAMPLES

In table I the samples on which the results of this investigation are based are grouped according to season; locality and method of capture. In a season are included all samples taken in the interval between the end of spawning time in the spring of one year and the end of spawning time in the spring of the following year. The locations of the more important regions from which fish were obtained are shown on the accompanying map (figure 1). The majority of the samples were taken from catches made by the commercial purse seine and gill net fisheries. The remainder were captured for the most part on the spawning grounds by means of beach seine, dip net, rake (a long pole with sharp needles along the lower part of one side) or jig (a line to which are attached several sharp hooks.

The usual method of obtaining samples from the catch was to scoop or shovel the fish into pails and in this way to avoid personal selection. Consequently, except for one or two doubtful cases, all samples may be regarded as random portions of the catch. For practical purposes, samples taken by purse seine, beach seine, dip net, rake and jig are comparable with each other and may be regarded as random portions of the schools from which they were drawn as the amount of selection caused by these various methods of capture is small. On the other hand, samples from the gill net fishery cannot be regarded as representative of the schools because of the selective action of gill nets (Hodgson 1933; Tester 1935b).

The two major purse seine fisheries, located near Saltspring island on the south-east coast and in Barkley sound on the west coast of Vancouver island have been sampled fairly regularly throughout each fishing season (October to January in the former; November to February in the latter). The sampling

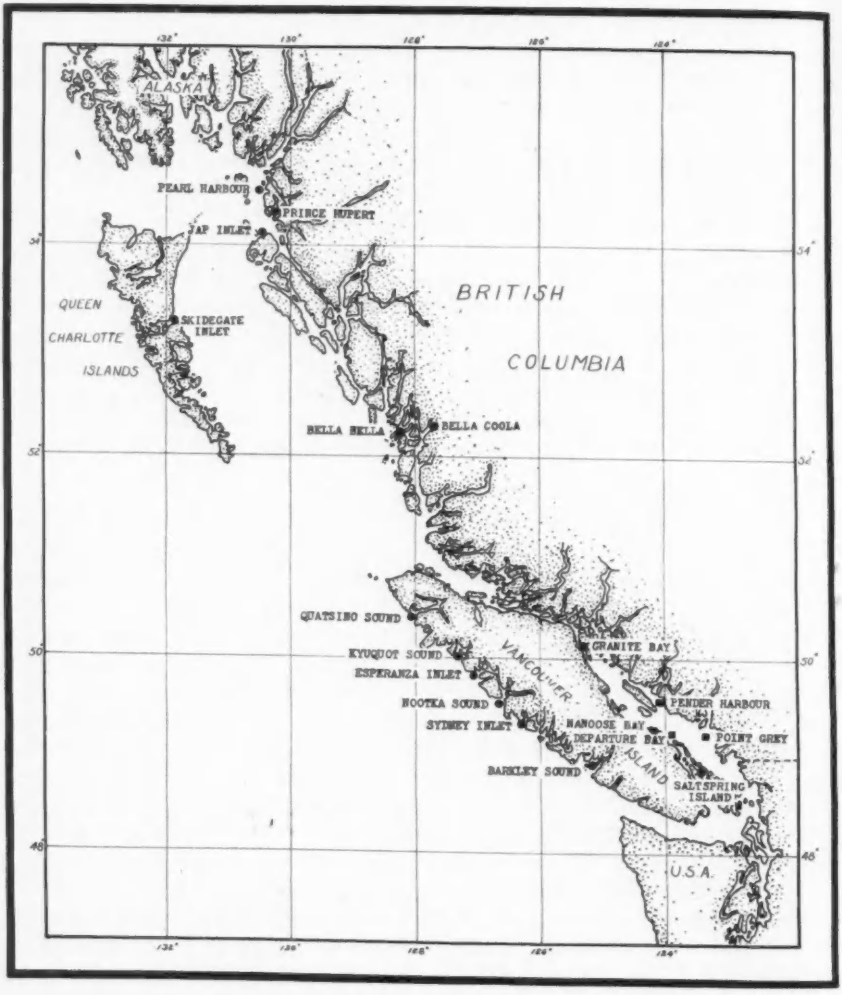

FIGURE 1.—Location of areas from which samples were obtained.

of the minor purse seine fisheries (Nanoose bay, Granite bay, Sydney inlet, Nootka sound, Esperanza inlet, Kyuquot sound, Quatsino sound, Jap inlet, Butler cove, Prince Rupert harbour, and Pearl harbour) which take place during the winter or prior to spawning time in the spring has been less complete.

The gill-netted samples were taken during the summer from point Grey, during the fall and winter from Pender harbour and during the spring from Departure and Nanoose bays. Samples of fish were also taken from the spawning grounds during the spring at Departure bay, Bella Bella, Bella Coola and Skidegate inlet.

The size of individual samples has been usually about 100 fish although smaller samples were taken prior to 1931-32 from the vicinity of Vancouver island and larger samples were taken in subsequent years from the more-distant localities.

The location of the fishing grounds, types of gear and methods of the commercial fisheries have been described in detail elsewhere (Tester 1935a).

Treatment of Samples

Various length measurements were made on the samples of herring listed in table I, using a measuring board similar to that described and illustrated by Rounsefell (1930). All distances were measured in millimetres from the tip of the closed lower jaw to the various end points. These measurements are not of the actual distances but rather of the distances as projected on the scale of the measuring board. The length measurements and also the various counts which were made are listed, defined and discussed below:

Standard length—the distance to the end of the silvery area on the caudal peduncle after the scales have been removed from that region. This may be converted into total length (the distance to the end of the caudal fin when its edges are held parallel to each other) by multiplying by the factor 1.185. The factor was calculated from total length measurements of 20 individuals in each millimetre category of standard length from 163 to 231 mm. inclusive.

Head length—the distance to the most posterior extremity of the bony edge of the opercle when the head is held touching the board over its entire lower surface (right side).

Length to the insertion of the dorsal fin—the distance to the base of the most anterior ray of the dorsal fin.

Vertebral count—the number of vertebrae between, but not including, the basioccipital and hypural bones. In samples collected prior to 1931-32 the vertebral columns were laid bare by removing the flesh with a scalpel. In samples collected during 1931-32 and in subsequent years, the fish were cooked for a few minutes in boiling water before removing the flesh and the cleaned vertebral columns were dried. The latter method gave greater precision of count but could not be applied satisfactorily to salted fish. For these the earlier method was used. Counts were repeated on all samples at least once and often twice. Abnormal vertebrae with either simple or complex fusion of centra were not included in the calculations. Minor abnormalities such as double spines which were frequently present in the posterior vertebrae but which did not involve the fusion of centra were included as normal. At the time of counting, the number of vertebrae between the basioccipital and the first closed haemal arch and the number from the first closed haemal arch to the hypural were

recorded and are designated as the pre-haemal or *abdominal* count and the post-haemal or *caudal* count respectively.

Keeled scale count—the number of scales with a definite keel between the base of the pelvic fins and the anus. As the keeled scales tended to become

Table I.--Giving a summary of information relative to samples of herring

Season	Locality of capture	Method of capture	Condition when measured	Number of samples	Total number of fish
1929-30	Strait of Georgia:- Swanson channel, Satellite channel	purse seine	fresh	10	745
	Barkley sound:- Uchucklesit harbour, Useless inlet, Effingham inlet	purse seine	fresh	20	905
1930-31	Strait of Georgia:- Swanson channel, Cowichan bay, Trincomali channel, Nanaimo	purse seine	fresh	12	595
	Strait of Georgia:- Departure bay	rake	fresh	1	39
	Barkley sound:- Uchucklesit harbour, Rainy bay, Sunshine bay, mouth of Effingham inlet	purse seine	fresh	5	262
	Nootka sound	purse seine	fresh	1	150
1931-32	Strait of Georgia:- Trincomali channel, Dodd narrows, Cowichan gap	purse seine	fresh	9	775
	Strait of Georgia:- Nanoose bay	purse seine	fresh	4	296
	Barkley sound:- Uchucklesit harbour, Vernon bay, Effingham inlet	purse seine	fresh	8	745
	Sydney inlet:- Shelter arm	purse seine	fresh	9	825
	Nootka sound:- Muchalat arm, Nootka sound	purse seine	fresh	4	393
	Kyuquot sound	purse seine	fresh	4	524
	Pearl harbour	purse seine	salted	1	200
	Jap inlet	purse seine	salted	1	200
1932-33	Strait of Georgia:- Point Grey	gill net	fresh(ice)	4	500
	Strait of Georgia:- Pender harbour	gill net	fresh(ice)	4	447
	Strait of Georgia:- Departure bay	gill net	fresh	2	176
	Strait of Georgia:- Horswell point	beach seine	fresh	1	557
	Strait of Georgia:- Trincomali channel, Swanson channel, Dodd narrows	purse seine	fresh	10	919
	Barkley sound:- Rainy bay, Warner bay	purse seine	fresh(ice)	7	820
	Sydney inlet:- Shelter arm, Matilda creek	purse seine	fresh	4	476
	Nootka sound:- Ewin creek, Bligh island, King's passage	purse seine	fresh	4	389
	Esperanza inlet:- Queen's cove	purse seine	fresh	2	200
	Kyuquot sound:- Blind entrance	purse seine	fresh	3	389
	Quatsino sound	purse seine	fresh(ice)	1	238
	Bella Bella:- Deer pass	dip net	salted	1	314
	Jap inlet	purse seine	salted	1	250
	Pearl harbour	purse seine	salted	1	254
1933-34	Strait of Georgia:- Point Grey	gill net	fresh(ice)	3	450
	Strait of Georgia:- Pender harbour	gill net	fresh(ice)	1	100
	Strait of Georgia:- Pender harbour	purse seine	fresh(ice)	1	100
	Strait of Georgia:- Swanson channel, Active pass, Porlier pass, Dodd narrows	purse seine	fresh	6	570
	Strait of Georgia:- Hammond bay	purse seine	fresh	1	100
	Strait of Georgia:- Nanoose bay	purse seine	fresh	1	100
	Quathiaski:- Granite bay	purse seine	fresh(ice)	1	100
	Barkley sound:- Sechart channel, Middle channel, Uchucklesit harbour, Rainy bay	purse seine	fresh(ice)	8	371
	Sydney inlet:- North arm	purse seine	fresh(ice)	2	200
	Nootka sound:- Nootka sound, Tahsis canal	purse seine	fresh(ice)	3	300
	Kyuquot sound:- Chamiss bay, Kyuquot sound	purse seine	fresh(ice)	2	147
	Quatsino sound	purse seine	fresh(ice)	2	200
	Bella Coola	jig	salted	1	37
	Butler cove	purse seine	salted	1	200
	Jap inlet	purse seine	salted	1*	249
1934-35	Strait of Georgia:- Point Grey	gill net	fresh(ice)	3	400
	Strait of Georgia:- Pender harbour	gill net	fresh(ice)	1	100
	Strait of Georgia:- Swanson channel, Trincomali channel	purse seine	fresh	8	786
	Strait of Georgia:- Nanoose bay	purse seine	fresh	1	115
	Strait of Georgia:- Nanoose bay	gill net	fresh	3	300
	Strait of Georgia:- Departure bay	rake	fresh	4	320
	Quathiaski:- Granite bay	purse seine	fresh(ice)	1	115
	Barkley sound:- Middle channel, Effingham inlet, Rainy bay, Pill point	purse seine	fresh	7	800
	Quatsino sound	purse seine	fresh(ice)	2	244
	Bella Bella:- Gullchuck inlet	drag seine	salted	1	199
	Jap inlet	purse seine	salted	1	168
	Butler cove	purse seine	salted	1	150
	Prince Rupert harbour	purse seine	salted	1	139
	Skidegate inlet	drag seine	salted	1	200

rudimentary towards the anus, the posterior end point was uncertain in many instances. Doubtful cases were omitted from the calculations.

Pectoral fin-ray count—the average of the number of unbranched rays in both pectoral fins as counted under a low power binocular microscope. The more ventral rays of the fins were sometimes branched almost to the bases but individual rays could usually be distinguished by close examination. In some cases the fins were stained in alizarin before the counts were made.

In addition to the various measurements and counts already listed, weight and sex determinations were made and scale samples were taken. The total *weight* of each fish was determined to the nearest gram by means of a Chatillon spring scale. *Sex* was determined by exposing the gonads with an incision of the body wall. The *scale sample* was taken from the side of each fish at the anterior part of the body. In 1931-32 and subsequent years, the scales were taken with somewhat more precision from small areas on both sides of the body at the tip of the flexed pectoral fins whenever this was possible. The scales were placed between the pages of small books where they were held in place by their own mucous material.

The *ages* of the fish were estimated from the scales without reference to the lengths. The methods of age estimation and the reliability of the results will be discussed elsewhere (Tester 1937). Ages are designated by Roman numerals. For example, a fish whose scale showed two winter rings and three summer bands is considered to be in its third year and is designated by III.

The Adjustment of Length Measurements of Salted Fish

All samples from localities north of Vancouver island were packed in wooden pails and salted for preservation during transportation. In order to determine the shrinkage in length which takes place as a result of salting, a series of 25 fresh herring, obtained from point Grey on July 8, 1935, were measured, serially numbered, and immersed in a saturated brine solution, similar to that found in the samples of salted fish. The fish were again measured on July 15, July 22 and August 5, 1935.

STANDARD LENGTH

The following figures show that mean standard length first decreased at the end of the first week of preservation and then increased slightly at the end of the second week, remaining constant thereafter: July 8—182.64; July 15—176.76; July 22—176.96; August 5—176.96 mm. As fish are usually measured about two weeks after preservation the mean shrinkage of 5.68 mm. (July 22) was considered to be the best estimate.

The data showed a general tendency for the amount of shrinkage to increase with standard length. The method of least squares (Tuttle and Satterly 1925, p. 228) was used to obtain a relationship between standard length of salted fish (y) and shrinkage (x), assuming the relationship to be linear. From the equation, $y = 0.0254\,x + 1.1847$, a correction graph was constructed and from this the following corrections, to be added to the standard length of the salted fish,

were obtained: 5 mm. between 131 and 170 mm.; 6 mm. between 171 and 210 mm.; 7 mm. between 211 and 249 mm. These corrections were applied to obtain the mean standard length of salted samples to render the results comparable with those measured in a fresh condition.

In obtaining length frequencies in three- or five-millimetre classes, the artificial nature of the correction factor resulted in the loss of a millimetre grouping interval with each increase in the factor, but this was compensated by multiplying the number of individuals in classes in which this occurred by an appropriate factor (depending on the size of the grouping interval) before calculating percentage frequencies.

HEAD LENGTH

As the head of the fish is composed mostly of bone, it is assumed that the amount of shrinkage in head length is negligible.

LENGTH TO THE INSERTION OF THE DORSAL FIN

As in the case of standard length, this character first decreased and then increased to a small extent as a result of salting: July 8—92.24; July 15—90.64; July 22—90.84; August 5—90.76 mm. The measurements of individual fish on July 22 showed a slight tendency for shrinkage to increase with dorsal insertion length but it was sufficiently small to be neglected. An average correction of 1.4 mm. to be added to the dorsal insertion length of salted fish was considered a sufficiently accurate adjustment.

RESULTS

The interpretation of the results of this paper are based on the principle that, under conditions of partial or complete isolation of a group of fish, slight peculiarities in body structure, induced by either environmental or hereditary factors, are preserved. Thus, small differences, showing only in an average of a large number of specimens, may arise between populations which intermingle only slightly or not at all and these will persist over a period of years. The reality or "significance" of these slight differences may be appraised with the help of statistical procedures based on the Theory of Probability. As Rounsefell (1930) has pointed out: "The relative importance of the parts played by heredity and environment in causing the constancy of these differences between populations is a moot question, but the important point at issue is not the cause of such differences, but rather their existence and extent." It might be added, however, that knowledge of the cause or causes of the differences would assist materially in interpreting their biological significance.

Total Vertebral Count

GRADATION OF VERTEBRAL COUNT WITH LATITUDE

In a preliminary paper (1933), the author has shown that during 1931-32 and 1932-33 within the waters of British Columbia, there was a gradation in

mean vertebral count with latitude which conformed with the general gradation along the west coast of North America pointed out first by Hubbs (1925) and later in more detail by Rounsefell (1930). The data for these two seasons, together with additional data for 1933-34 and 1934-35, are given in table II and are shown graphically in figure 2. It will be observed that, aside from minor irregularities, the gradation has persisted for four seasons, fish from southern waters having a low mean count and those from northern waters having a higher mean count each year. This gradation and its persistence within the waters of the province suggest that intermingling of herring between areas, particularly

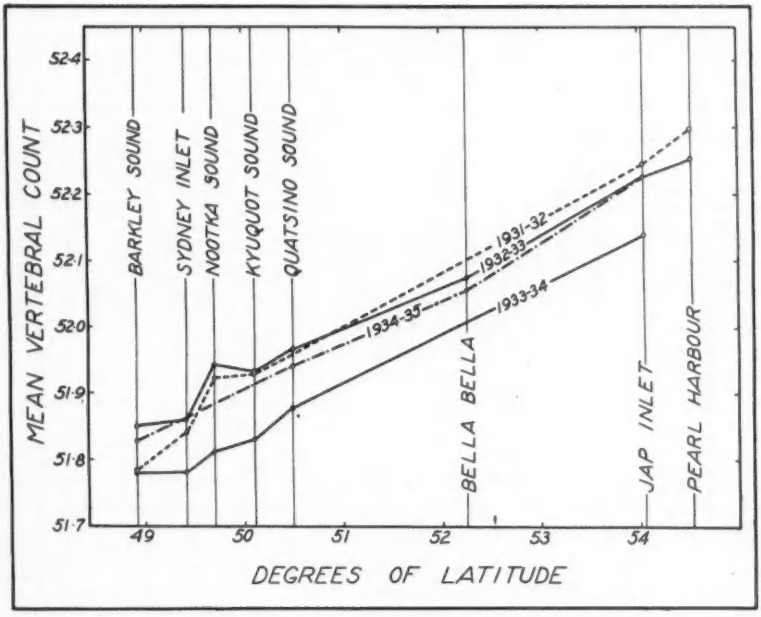

FIGURE 2.—Gradation in mean vertebral count with latitude in four seasons.

those separated by more than 60 nautical miles (ca. 110 km.), is slight, and also, by inference, that migration in a southerly or northerly direction along the coast is limited.

Standard errors of the means (*S.E.*), calculated according to the usual formula ($s/\sqrt{n}$) are included in table II. The differences between the mean counts from Barkley sound, the most southern, and from Jap inlet and Pearl harbour, the two most northern areas, were tested in all four years to determine whether or not they were statistically significant. The standard errors of the differences were calculated from a pooled estimate of the variances (Fisher 1932,

p.115). In all six comparisons in the four years, the differences between the mean counts in the southern and northern localities were highly significant for they were all between 6.4 and 9.5 times their own standard errors.

Comparisons of the means in more closely-situated localities yield some differences which are significant and others which are of doubtful or of no statistical significance. From an examination of figure 2 or table II, however, it may be seen that the mean count in any one locality varies considerably from year to year, and, further, that in one year (1933-34) all of the means were relatively low. Before comparisons are made between the counts in more closely-situated localities, and before the criteria of statistical significance are accepted as proof of population differences in vertebral count, the sources of this variation should first be determined.

Table II.--Giving mean vertebral counts of herring from various localities in British Columbia for four seasons

Locality	Approximate latitude	1931-32		1932-33		1933-34		1934-35	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Barkley sound	48° 55'	51.783	0.053	51.851	0.022	51.782	0.025	51.829	0.022
Sydney inlet	49° 25'	51.841	0.036	51.860	0.031	51.781	0.051	--	--
Nootka sound	49° 42'	51.923	0.039	51.943*	0.027	51.812	0.037	--	--
Kyuquot sound	50° 6'	51.930	0.038	51.931	0.032	51.830	0.053	--	--
Quatsino sound	50° 29'	--	--	51.965	0.042	51.878	0.049	51.941	0.040
Bella Bella	52° 15'	--	--	52.075	0.039	--	--	52.056	0.048
Jap inlet	54° 3'	52.245	0.049	52.228	0.040	52.139†	0.033	52.228*	0.036
Pearl harbour	54° 32'	52.298	0.047	52.254	0.040	--	--	--	--

* including Esperanza inlet.
† including Butler cove.

VARIATION IN MEAN VERTEBRAL COUNT WITH YEAR CLASS

In the mean vertebral count of a sample are included the counts of its several year class components. If, as found by Lea (1919) and Runnstrøm (1933) for the Atlantic herring, and by Rounsefell (1930) for the Pacific herring, the mean counts of two year classes from the same locality may differ significantly, differences in the mean counts of the composite samples both between or within localities may reflect merely differences or changes in age composition. Therefore, it is essential to determine the extent of this variation in the British Columbia herring.

In table III the vertebral counts of the various year classes are given, omitting those based on less than 25 individuals. The sum (S) of the squares of the deviations of individual variates (x) from the mean ($\bar{x}$) is included for each year class in each locality. It may be seen that there is considerable variation between the mean vertebral counts of the various year classes in any one locality. Perusal of table IV, in which are given the results of statistical tests of some of the more obvious differences, shows that many of these are very significant. For example, the difference of 0.199 vertebrae between the 1931 and 1932 year classes in the Saltspring island samples is 4.4 times its standard

error and hence is very unlikely to have been the result of chance. As differences such as these are present, comparisons of mean vertebral counts between localities should be confined to one year class. The low values obtained in 1933-34 (figure 2) were caused to a large extent by the low mean count of the 1931 year class (table III) which, as will be shown elsewhere (Tester 1937), predominated in most localities.

For several years, investigators have been attempting to explain variation in vertebral count. Recently Rounsefell and Dahlgren (1932) have established a negative correlation between the mean vertebral count of successive year classes in Prince William sound, Alaska, and mean air temperatures during the com-

Table III.--Giving the mean vertebral counts of different year classes of herring from the various localities

Locality	Year class	Number of vertebrae								No.	Mean	$S(x-\bar{x})^2$
		48	49	50	51	52	53	54	55			
Saltspring island	1925	-	-	3	20	38	8	1	-	70	51.771	40.343
Saltspring island	1926	1	-	4	36	75	21	-	-	137	51.803	83.679
Saltspring island	1927	-	-	9	125	259	49	1	-	443	51.792	194.894
Saltspring island	1928	1	3	12	143	336	73	4	-	572	51.827	305.865
Saltspring island	1929	1	1	12	208	433	74	1	-	730	51.777	322.604
Saltspring island	1930	-	-	7	112	267	55	3	-	444	51.854	197.484
Saltspring island	1931	-	-	7	194	320	59	-	-	580	51.743	242.722
Saltspring island	1932	-	-	2	74	197	53	3	-	329	51.942	145.903
Departure bay	1928	-	-	-	13	22	3	2	-	40	51.850	23.100
Departure bay	1929	-	-	3	42	64	16	-	-	125	51.744	61.809
Departure bay	1930	-	-	1	16	31	7	-	-	55	51.800	24.800
Departure bay	1931	-	-	-	20	60	10	1	-	91	51.912	33.297
Departure bay	1932	-	-	3	34	76	21	-	-	134	51.858	64.306
Departure bay*	1927	-	-	-	7	19	4	-	-	30	51.900	10.700
Departure bay*	1928	-	-	1	14	38	5	-	-	58	51.810	20.913
Departure bay*	1929	-	-	-	13	42	4	-	-	59	51.847	15.628
Hammond bay	1931	-	-	1	10	23	5	-	-	39	51.821	17.744
Nanoose bay	1927	-	-	-	11	11	3	-	-	25	51.680	11.440
Nanoose bay	1928	-	-	-	8	40	6	1	-	55	52.000	18.000
Nanoose bay	1929	-	-	-	17	19	10	-	-	46	51.848	25.935
Nanoose bay	1931	-	-	1	34	70	14	1	-	120	51.833	52.667
Nanoose bay	1932	-	-	-	8	34	6	-	-	48	51.958	13.917
Nanoose bay*	1929	-	-	1	24	54	4	1	-	84	51.762	31.238
Nanoose bay*	1930	-	-	2	22	41	8	-	-	73	51.753	33.562
Nanoose bay*	1931	-	-	1	34	48	1	-	-	84	51.583	24.417
Granite bay	1931	-	-	3	28	42	16	3	-	92	51.870	66.435
Granite bay	1932	-	-	-	6	44	14	2	-	66	52.182	25.818
Point Grey*	1927	-	-	1	8	16	5	-	-	30	51.833	16.167
Point Grey*	1928	-	-	-	30	89	34	1	-	154	52.039	67.766
Point Grey*	1929	-	-	3	60	222	120	13	-	418	52.191	228.689
Point Grey*	1930	-	-	2	44	116	51	4	-	217	52.051	118.442
Point Grey*	1931	-	-	4	49	75	22	-	-	150	51.767	78.833
Point Grey*	1932	-	-	-	8	32	7	-	-	47	51.979	14.979
Pender harbour	1931	-	-	2	17	34	4	1	-	58	51.741	29.121
Pender harbour*	1930	-	-	1	20	19	8	-	-	48	51.708	27.917
Pender harbour*	1931	-	-	1	24	37	6	-	-	68	51.706	28.118
Barkley sound	1926	-	-	1	14	19	3	-	-	37	51.649	16.432
Barkley sound	1927	-	-	2	65	120	19	-	-	206	51.757	79.864
Barkley sound	1928	-	-	1	55	122	29	-	-	207	51.865	84.213
Barkley sound	1929	-	-	-	72	172	42	1	-	287	51.902	115.268
Barkley sound	1930	-	-	4	150	352	64	-	-	570	51.835	214.498
Barkley sound	1931	1	-	9	219	407	68	1	-	705	51.757	301.523
Barkley sound	1932	-	-	1	88	225	39	1	1	355	51.870	138.039
Sydney inlet	1927	-	-	4	45	125	17	1	-	192	51.823	75.979
Sydney inlet	1928	-	-	4	63	136	16	-	-	219	51.749	81.187
Sydney inlet	1929	-	-	2	51	137	26	1	-	217	51.876	85.641
Sydney inlet	1930	-	-	1	23	90	19	-	-	133	51.955	45.729
Sydney inlet	1931	-	-	4	40	71	13	1	-	129	51.744	64.558

Table III (continued)

Locality	Year class	Number of vertebrae 48	49	50	51	52	53	54	55	No.	Mean	$S(x-\bar{x})^2$
Nootka sound	1927	-	-	3	29	52	12	-	-	96	51.760	47.490
Nootka sound	1928	-	-	-	36	98	22	1	-	159	51.912	62.767
Nootka sound	1929	-	-	2	51	140	39	2	-	234	51.949	105.385
Nootka sound	1930	-	-	1	40	139	37	3	-	220	52.005	92.995
Nootka sound	1931	-	-	3	53	110	18	-	-	184	51.782	73.864
Esperanza inlet	1928	-	-	-	16	22	5	-	-	43	51.744	18.184
Esperanza inlet	1929	-	-	1	11	48	13	-	-	73	52.000	28.000
Esperanza inlet	1930	-	-	-	7	28	8	-	-	43	52.023	14.977
Kyuquot sound	1927	-	-	-	19	42	12	1	-	74	51.932	34.662
Kyuquot sound	1928	-	-	-	32	99	24	-	-	155	51.948	55.587
Kyuquot sound	1929	-	-	2	53	159	37	2	-	253	51.937	104.988
Kyuquot sound	1930	-	-	1	29	110	17	-	-	157	51.911	48.752
Kyuquot sound	1931	-	-	1	28	59	14	-	-	102	51.843	43.490
Quatsino sound	1927	-	-	-	22	79	22	1	-	124	52.016	47.968
Quatsino sound	1928	-	-	1	31	57	13	1	-	103	51.825	48.855
Quatsino sound	1929	-	-	-	14	77	16	1	-	108	52.037	33.852
Quatsino sound	1930	-	-	-	5	20	1	-	-	26	51.846	5.384
Quatsino sound	1931	-	-	-	18	54	10	1	-	83	51.928	31.566
Quatsino sound	1932	-	-	-	32	62	17	-	-	111	51.865	46.973
Bella Bella	1927	-	-	1	17	58	27	1	-	104	52.096	51.038
Bella Bella	1928	-	-	1	9	49	14	1	-	74	52.068	30.662
Bella Bella	1929	-	-	-	21	77	24	1	-	123	52.041	48.797
Bella Bella	1931	-	-	-	24	56	26	1	-	107	52.037	53.851
Bella Bella	1932	-	-	-	4	26	10	-	-	40	52.150	13.100
Skidegate inlet	1928	-	-	-	8	48	16	-	-	72	52.111	23.111
Skidegate inlet	1930	-	-	1	3	19	13	-	-	36	52.222	18.222
Skidegate inlet	1932	-	-	-	7	23	16	1	-	47	52.234	24.426
Jap inlet	1927	-	-	-	8	55	36	3	-	102	52.333	44.667
Jap inlet	1928	-	1	1	15	74	41	2	-	134	52.187	72.336
Jap inlet	1929	-	-	2	26	163	92	2	-	285	52.232	118.716
Jap inlet	1930	-	-	-	3	28	11	-	-	42	52.190	12.476
Jap inlet	1931	-	-	1	29	96	32	-	-	158	52.006	64.994
Jap inlet	1932	-	-	1	3	35	23	3	-	65	52.369	33.139
Butler cove	1928	-	-	-	1	14	9	1	-	25	52.400	10.000
Butler cove	1929	-	-	-	2	55	25	-	-	82	52.280	20.549
Butler cove	1931	-	-	-	27	93	38	-	-	158	52.070	64.234
Prince Rupert harbour	1929	-	-	-	4	17	8	-	-	29	52.138	11.448
Prince Rupert harbour	1931	-	-	1	2	30	10	-	-	43	52.139	15.163
Prince Rupert harbour	1932	-	-	-	5	20	11	-	-	36	52.167	15.000
Pearl harbour	1926	-	-	-	4	21	11	1	-	37	52.243	16.811
Pearl harbour	1927	-	-	-	10	77	52	3	-	142	52.338	57.775
Pearl harbour	1928	-	-	-	8	60	24	4	-	96	52.250	42.000
Pearl harbour	1929	-	-	-	13	80	42	2	-	137	52.241	55.051

* gill-netted fish.

bined months of March, April, May and June in the same locality. They also show that there is a direct correlation between mean air temperature and mean water temperature for the same four months in successive years. This indicates that the temperature of the water during March, April, May and June, when the vertebral column is in the process of formation, may play an important part in determining the mean vertebral count of each year brood. High water temperatures are related to low vertebral counts, and conversely, low water temperatures are related to high vertebral counts. Runnstrøm (1933), from observations of the variation in mean vertebral counts and spring water temperature along the coast of Norway, arrived at a similar conclusion for the Norwegian spring-spawning herring.

The possibility of a relationship between mean vertebral count and temperature was investigated in British Columbia. Because of the lack of adequate

water temperature series it was again necessary to make use of air temperature data. The mean vertebral counts of seven year classes (1926 to 1932 inclusive) for Jap inlet, Barkley sound and Saltspring island, were compared with mean air temperatures published by the Meteorological Service of Canada for the north shore of British Columbia, northwest coast of Vancouver island and southeast coast of Vancouver island, respectively. The data are shown in Table V and those for Jap inlet are portrayed graphically in figure 3. Correlation coefficients (r) were calculated according to the formula given by Fisher (1932, p. 161). The significance of r was tested by calculating the statistic t and comparing its value with those in Fisher's table of t, calculated at different probabilities (P).

Table IV.--Showing significant differences between mean vertebral counts of different year classes in the same locality

Locality	Year classes compared	Difference between means	$S.E._D$	$D/S.E._D$
Saltspring island	1930 : 1931	0.111	0.041	2.7
Saltspring island	1931 : 1932	0.199	0.045	4.4
Point Grey*	1929 : 1930	0.140	0.062	2.3
Point Grey*	1929 : 1931	0.424	0.070	6.1
Barkley sound	1929 : 1931	0.145	0.045	3.2
Barkley sound	1930 : 1931	0.078	0.036	2.2
Sydney inlet	1928 : 1930	0.206	0.066	3.1
Jap inlet	1929 : 1931	0.226	0.064	3.5

* gill-netted fish.

Table V.--Showing mean vertebral counts of six year classes and mean average air temperatures in degrees (F.) for the months of March, April, May and June in the corresponding years

Year class	Jap inlet		Barkley sound		Saltspring island	
	Mean air temp.	Mean vertebral count	Mean air temp.	Mean vertebral count	Mean air temp.	Mean vertebral count
1926	48¾	(16) 52.000	50¾	(37) 51.649	54¼	(137) 51.803
1927	45	(102) 52.333	47¼	(206) 51.757	49¼	(443) 51.792
1928	46½	(134) 52.187	49¼	(207) 51.865	51	(572) 51.827
1929	46¼	(285) 52.232	47¼	(287) 51.902	49¾	(730) 51.777
1930	46¼	(42) 52.190	48¼	(570) 51.835	50¾	(444) 51.854
1931	46¾	(158) 52.006	51½	(705) 51.757	51½	(580) 51.743
1932	45¾	(65) 52.369	51	(355) 51.870	51	(329) 51.942

In the Jap inlet series, a fairly significant negative correlation was obtained between air temperature and vertebral count ($r=-0.833$; $P=0.02$), thus substantiating the results obtained by Rounsefell and Dahlgren in Alaska. In Barkley sound samples, a weak negative correlation was also obtained ($r=-0.37$) which was not significant ($P=0.40$), whereas in the Saltspring island samples, there was no correlation ($r=0.00$). There are at least two reasons why a significant correlation is obtained at Jap inlet and not at Saltspring island and Barkley sound, even though in both the vertebral count may be related to water temperatures prevailing at the time of development and formation of the vertebral column. In the vicinity of Jap inlet, herring spawn mostly along the

exposed coast whereas near Saltspring island and in Barkley sound, they spawn mostly in protected waters. In the latter there is not necessarily a close correlation between spring water temperatures and general spring air temperatures (no significant correlation was obtained for Departure bay). In northern waters the spawning period is much shorter than in southern waters. During the protracted spawning period in the latter, which lasts for at least two months, many individual spawnings occur on the same and on different grounds and presumably under different temperature conditions (the water is warming relatively rapidly during the period) in each locality. Thus the mean count for a year class will depend mostly on the heaviest spawning that has taken place at a particular temperature and will not necessarily be related to average temperatures over the whole spawning period.

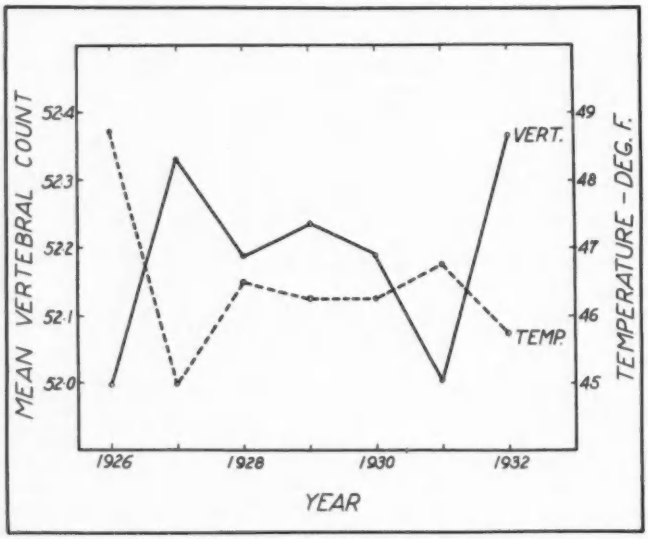

FIGURE 3.—Inverse relationship between mean air temperature during the months of March, April, May and June, and mean vertebral count of successive year classes at Jap inlet.

From these considerations it may be concluded that the results for Jap inlet support those of Rounsefell and Dahlgren in Alaska in indicating strongly that variation in the mean vertebral count of successive year classes in the same locality is related in some way to variation in water temperature during the period of spawning and early development and that those for Saltspring island and Barkley sound do not necessarily contradict the truth of this deduction. The negative correlation between mean vertebral count and temperature also gives a possible explanation of the gradation of vertebral count with latitude, the lower temperatures to the north resulting in higher vertebral counts.

VARIATION IN MEAN VERTEBRAL COUNT WITH AGE

The possibility exists that the mean vertebral count of a year class of herring in the schools of mature fish may either increase or decrease as the year class becomes older. A year class in the fishery is not stable for, in its early years, new recruits reaching sexual maturity for the first time are added to its ranks and, in its later years, old fish are constantly dropping out. Those fish which join the schools of mature fish late or which die early may be characterized by a low or high vertebral count and their addition or loss would result in a gradual change in the mean vertebral count of the year class as a whole.

Rounsefell and Dahlgren (1935) compared the mean counts of the 1926 and 1927 year classes from eight localities in Alaska at the age of IV with means of the same year classes in the same localities at the age of V. The unweighted grand mean at IV was 52.417 and at V, 52.459. The difference of 0.042 vertebrae was not significant ($P=0.12$).

Similar comparisons have been made for the British Columbia herring. In table VI, the means of vertebral counts of the same year classes in the same localities are compared at ages III and IV, IV and V, V and VI, respectively. They include all possible comparisons of means which are based on more than 25 individuals, except the 1929 year class in the Saltspring island samples at ages IV and V, and V and VI. These were omitted for a reason which will become apparent later.

Comparisons of the grand means in the table show that the older fish have a slightly higher vertebral count than the younger fish. The mean differences between IV's and III's, V's and IV's, VI's and V's are 0.033, 0.042 and 0.082, respectively, and these are of similar magnitude and in the same direction as the differences between V's and IV's of 0.042 vertebrae reported by Rounsefell and Dahlgren. On testing the results by the method of Fisher (1932, p. 112) none of the grand mean differences were found to differ significantly from 0 ($P=0.23$, 0.26 and 0.21 respectively). However, on combining the results of all three sets of comparisons and comparing the grand mean at age $n+1$ with that at age n, a difference of 0.043 vertebrae was obtained with a probability value ($P=0.03$) which indicates the statistical significance of the results.

From the above, it may be concluded that in British Columbia there is a small but apparently significant increase in the mean vertebral count of a year class with age. If the vertebral counts of fish of the same year class in the same locality but at different ages are combined and compared with similar data from another locality, the possibility exists that statistically significant differences in vertebral count may arise merely because of differences in the proportions of fish of different ages making up the mean count of the year class. On the other hand, if comparisons are confined to one year class at one age, the number on which each average is based is reduced considerably. As the increase in mean count with age is slight, and as the number of individuals in a year class in a given season is usually too small to establish its significance, there is no great danger of drawing wrong conclusions from differences of the higher level of significance when comparing the vertebral counts of a year class containing similar age groups in two localities.

No attempt is made to explain the cause of this phenomenon except to suggest that it may be related to a differential addition of new recruits or a differential mortality in respect to vertebral count.

Table VI.--Comparing the means of vertebral counts of the same year classes at different ages in the various localities

Locality	Year class	Mean vertebral count at age		Difference
		III	IV	IV - III
Saltspring island	1927	51.747	51.851	+0.104
Saltspring island	1928	51.714	51.939	+0.225
Saltspring island	1929	51.741	51.783	+0.042
Barkley sound	1929	51.822	51.861	+0.039
Sydney inlet	1929	51.938	51.820	-0.118
Nootka sound	1929	51.959	51.935	-0.024
Kyuquot sound	1929	51.886	51.986	+0.100
Jap inlet	1929	52.396	52.193	-0.203
Pearl harbour	1929	52.308	52.225	-0.083
Saltspring island	1930	51.881	51.784	-0.097
Barkley sound	1930	51.864	51.774	-0.090
Nootka sound	1930	52.000	52.029	+0.029
Saltspring island	1931	51.694	51.804	+0.110
Nanoose bay	1931	51.861	51.765	-0.096
Granite bay	1931	51.800	52.000	+0.200
Point Grey*	1931	51.593	51.804	+0.211
Barkley sound	1931	51.738	51.783	+0.045
Quatsino sound	1931	51.875	51.961	+0.086
Jap inlet	1931	51.954	52.069	+0.115
Butler cove	1931	52.040	52.096	+0.056
Grand mean		51.890	51.923	+0.033
		IV	V	V - IV
Saltspring island	1926	51.600	52.020	+0.420
Saltspring island	1927	51.851	51.875	+0.024
Saltspring island	1928	51.939	52.000	+0.061
Barkley sound	1928	51.794	51.923	+0.129
Sydney inlet	1928	51.787	51.710	-0.077
Nootka sound	1928	51.982	51.761	-0.221
Kyuquot sound	1928	51.940	51.964	+0.024
Jap inlet	1928	52.174	52.250	+0.076
Pearl harbour	1928	52.237	52.259	+0.022
Point Grey*	1929	52.163	52.144	-0.019
Barkley sound	1929	51.861	51.981	+0.120
Jap inlet	1929	52.193	52.162	-0.031
Saltspring island	1930	51.784	51.863	+0.079
Point Grey*	1930	52.074	52.080	+0.006
Barkley sound	1930	51.774	51.781	+0.007
Grand mean		51.943	51.985	+0.042
		V	VI	VI - V
Saltspring island	1927	51.767	51.905	+0.138
Jap inlet	1927	52.322	52.393	+0.071
Pearl harbour	1927	52.350	52.322	-0.028
Point Grey*	1928	51.970	52.194	+0.224
Barkley sound	1928	51.923	51.804	-0.119
Point Grey*	1929	52.144	52.351	+0.207
Grand mean		52.079	52.161	+0.082

* gill-netted fish.

VARIATION IN MEAN VERTEBRAL COUNT WITH SEX

To determine whether or not the mean vertebral count of the males and females of a year class differed significantly from each other, the best represented year classes of the Saltspring island samples were investigated. Confining the test to samples containing more than 25 individuals (males and females combined) 30 comparisons, including six year classes from 1927 to 1932 at age III, were

available. The unweighted grand mean for males was 51.814 and for females 51.841. The difference of 0.027 vertebrae did not differ significantly from 0 ($P = 0.56$), thereby agreeing with the results of Rounsefell and Dahlgren (1935). In comparing vertebral counts, therefore, it is not necessary to segregate the sexes.

VARIATION IN VERTEBRAL COUNT WITH LENGTH

Within a year class there appears to be a slight tendency for the larger fish to have higher vertebral counts. To illustrate this, the average lengths of herring with vertebral counts of 51, 52 and 53 have been calculated for samples from the Saltspring island fishery (table VII). Comparisons have been limited

Table VII.--Comparing the mean lengths of herring of the same year class but with different vertebral counts for the Saltspring island samples

Season	Year class	Age	Mean length at vertebral counts of		Difference
			51	52	52 - 51
1929-30	1927	III	183.0	185.6	+2.6
1929-30	1926	IV	196.9	200.7	+3.8
1930-31	1928	III	180.0	181.6	+1.6
1930-31	1927	IV	195.3	195.7	+0.4
1931-32	1929	III	179.4	181.1	+1.7
1931-32	1928	IV	192.3	194.4	+2.1
1932-33	1930	III	179.5	181.7	+2.2
1932-33	1929	IV	194.5	195.7	+1.2
1933-34	1931	III	179.9	182.3	+2.4
1933-34	1930	IV	196.2	193.1	-3.1
1934-35	1932	III	184.6	190.7	+6.1
1934-35	1931	IV	197.6	197.9	+0.3
Grand mean			188.27	190.04	+1.77
			52	53	53 - 52
1930-31	1928	III	185.6	188.8	+3.2
1930-31	1927	IV	195.7	195.6	-0.1
1931-32	1928	IV	194.4	196.3	+1.9
1932-33	1930	III	181.7	181.6	-0.1
1932-33	1929	IV	195.7	196.3	+0.6
1933-34	1931	III	182.3	182.5	+0.2
1934-35	1932	III	190.7	187.7	-3.0
1934-35	1931	IV	193.1	199.7	+6.6
Grand mean			189.90	191.06	+1.16

to year classes represented by 25 or more individuals at each vertebral count. In the first series of comparisons, the grand mean length of fish with 51 vertebrae is 188.27 and of fish with 52 vertebrae, 190.04 mm. Similarly, in the second series of comparisons, the grand mean length of fish with 52 vertebrae is 189.90 and, with 53 vertebrae, 191.06 mm. The difference of 1.77 mm. between the 51's and 52's is significantly different from 0 with a P value of 0.02. The difference of 1.16 mm. between the 52's and 53's is not statistically significant ($P = 0.31$), but the numbers on which the averages are based and the number of comparisons are both less than in the first series. Similar results have been obtained from similar series of comparisons in other localities.

The results of Thompson (1917) for herring from Nanaimo were indicative of a similar correlation between length and vertebral count. Hubbs (1925)

also showed that the larger individuals had a higher mean count than the smaller in a sample of fish in their first year from San Francisco bay. On the other hand, Ford (1930) found that in Plymouth herring in their first year, the mean vertebral count decreased with increase in length and that the larger individuals were in a more advanced stage of metamorphosis. Thompson suggests that the correlation might be the result of a differential growth rate. Hubbs believes that the larger fish with the higher vertebral count are those which developed earlier in the season under lower temperature conditions (spawning takes place in the winter and spring). A similar explanation might be applied to Ford's results as the fish which he examined were spawned in the fall and winter (Ford 1933) when the temperature was falling (Ford 1929). In this case the larger fish with the lower counts are those which developed earlier in the season under higher temperature conditions. The same explanation may be applicable to the present results for fish of ages III and IV but it is necessary to assume that the larger size attained by fish with a longer growth period in the first year is maintained in subsequent years. The validity of this assumption has not been determined.

Because of this correlation and because of the selective action of gill nets, the mean counts of the younger age groups will be slightly higher in gill-netted samples than in the population from which they were drawn.

HOMOGENEITY OF VERTEBRAL DATA FROM PARTICULAR LOCALITIES

Buchanan-Wollaston (1933) has shown the applicability of Fisher's "Analysis of Variance" to racial problems in testing a set of data for heterogeneity. This procedure was used to determine whether vertebral data yielded any evidence of the presence of more than one population in each locality. The methods of computation of Buchanan-Wollaston, set forth in tabular form by Rounsefell and Dahlgren (1935), were followed. Samples with variances which obviously did not conform with the normal distribution were discarded. The mean squares "between means" of samples were compared with the mean squares "within samples" by dividing the larger mean square by the smaller, thus obtaining the F value of Snedecor (1934), and comparing this with values in Snedecor's Table of F calculated at probabilities of 0.05 and 0.01 for corresponding numbers of "degrees of freedom". Values which could not be obtained either directly or by interpolation from the table were calculated from z values of Fisher (1932, p. 213).

The results of applying the above procedure to vertebral data of the 1929 year class in all seasons (1931-32 to 1934-35) for several localities are given in table VIII (under columns headed "degrees of freedom" and "mean squares" the first value refers to the comparison between means and the second to that within samples). It will be seen that in each case, the observed F value is less than that calculated at a probability of 0.05. Similar results were obtained with all other year classes which were tested in the various localities with the exception of that of 1931 at Saltspring island, where the observed F (1.82) exceeded slightly the calculated value (1.79). As these results are based on one year class in several seasons they suggest, although they do not prove, that the

vertebral material in each locality is homogeneous and that but one population in each is being sampled with the possible exception of that of Saltspring island.

As the vertebral count of a year class tends to increase with age, it might be expected that the essential heterogeneity of the data would be demonstrated if a much larger amount of material were gathered, even though but one population be present in the same locality from year to year. Further examination of the 1931 year class at Saltspring island shows that the mean count at age III in 1933-34 was 51.694 whereas at age IV in 1934-35 it was 51.804. The difference of 0.110 vertebrae between these two means is 2.0 times its own standard error (0.054), corresponding to a probability of 0.05. Thus the apparent heterogeneity of the vertebral data of this year class might have resulted from this change with age, for the "Analysis of Variance" gave negative results when the data of 1933-34 and 1934-35 were tested separately.

Table VIII.--Analysis of vertebral data of the 1929 year class in all seasons for several localities

Locality	Degrees of freedom	Mean squares	Observed F	Calculated F (P=0.05)
Saltspring island	31; 689	0.4037; 0.4362	1.08	1.62
Point Grey*	9; 402	0.9424; 0.5432	1.73	1.91
Barkley sound	19; 267	0.4804; 0.3965	1.21	1.65
Sydney inlet	11; 203	0.5521; 0.3895	1.42	1.84
Nootka sound	10; 221	0.2514; 0.4650	1.85	2.54
Kyuquot sound	8; 246	0.1485; 0.4217	2.84	2.93
Quatsino sound	3; 104	0.0862; 0.3230	3.75	8.53
Jap inlet-Butler cove	5; 361	0.6260; 0.3776	1.66	2.24

* gill-netted fish.

On examining the mean values of the 1929 year class at Saltspring island in 1931-32 (51.741), 1932-33 (51.783), 1933-34 (51.953) and 1934-35 (51.667), it was found that the mean in 1933-34 differed from those in the preceding years and that in the following year by 2.4, 1.9 and 2.4 standard errors respectively, even though the combined material of all seasons was not heterogeneous according to the "Analysis of Variance" (table VIII). While the latter test is more stringent than that used in comparing means, as it takes into consideration the variation of sample means about the grand mean, nevertheless the results suggest that the material of 1933-34 was different from that in other years. The difference cannot be accounted for wholly by the increase in vertebral count with age, for the mean in 1933-34 at age V was considerably higher than that in 1934-35 at age VI. It was also noted that the V's in 1933-34 had a smaller average length (199 mm.) than V's in other years from 1929-30 to 1934-35 (206, 203, 203, 206 and 206 mm.). These results suggest the infiltration of small fish with a high vertebral count to the Saltspring island population in 1933-34.

As a working hypothesis, it will be assumed that but one population is present in each locality both during one season and from year to year. It must be borne in mind, however, that the Saltspring island population may be heterogeneous and also that in several localities the material on hand is not sufficient to adequately analyze the populations.

SEGREGATION OF LOCAL POPULATIONS BY MEANS OF VERTEBRAL COUNTS

Application of the "Analysis of Variance" to samples of the 1929 year class in 1932-33 (IV's), from all localities which have been investigated, gives definite proof of the heterogeneity of the material and hence of the presence of more than one population in all waters of the province. In this test, the mean square "between means" was 1.4876 (40 degrees of freedom) and that "within samples" was 0.4242 (1735 degrees of freedom). The resultant F value of 3.51 was far above those calculated at probabilities of both 0.05 and 0.01 (1.40 and 1.60 respectively). It remains therefore to compare the data in the various localities to segregate the populations which are present.

Table IX.--Comparing the vertebral data of the same year class in the various localities

Localities compared	Year class	D	S.E.$_D$	D/S.E.$_D$
Saltspring island: point Grey*	1928	0.212	0.065	3.3
Saltspring island: point Grey*	1929	0.414	0.042	9.9
Saltspring island: point Grey*	1930	0.197	0.057	3.5
Saltspring island: Nanoose bay	1928	0.173	0.101	1.7
Saltspring island: Granite bay	1932	0.240	0.089	2.7
Saltspring island: Barkley sound	1929	0.125	0.046	2.7
Saltspring island: Quatsino sound	1929	0.260	0.067	3.9
Saltspring island: Bella Bella	1931	0.294	0.069	4.3
Saltspring island: Jap inlet	1927	0.541	0.073	7.4
Point Grey*: Nanoose bay*	1929	0.429	0.086	5.0
Point Grey*: Departure bay*	1929	0.344	0.102	3.4
Point Grey*: Pender harbour*	1930	0.343	0.119	2.9
Barkley sound: Quatsino sound	1927	0.259	0.071	3.6
Barkley sound: Quatsino sound	1929	0.135	0.070	1.9
Barkley sound: Quatsino sound	1931	0.171	0.076	2.2
Barkley sound: Bella Bella	1931	0.280	0.069	4.1
Barkley sound: Jap inlet	1929	0.330	0.054	6.1
Sydney inlet: Kyuquot sound	1928	0.199	0.064	3.1
Sydney inlet: Bella Bella	1928	0.319	0.083	3.8
Nootka sound: Bella Bella	1931	0.255	0.081	3.2
Kyuquot sound: Bella Bella	1931	0.194	0.095	2.0
Quatsino sound: Bella Bella	1928	0.243	0.101	2.4
Quatsino sound: Bella Bella	1932	0.285	0.117	2.4
Bella Bella: Jap inlet	1927	0.237	0.095	2.5
Bella Bella: Jap inlet	1929	0.191	0.069	2.8
Bella Bella: Pearl harbour	1927	0.242	0.087	2.8

* gill-netted fish.

As the vertebral data of each year class from individual localities are assumed to be homogeneous, significant differences between that of two localities may be detected by comparing the differences between the weighted means in each with their own standard errors. Because of the sources of variation pointed out in preceding sections, differences which are between 2 and 3 times their standard errors are considered as "approaching statistical significance" and those which are 3 or more times their standard errors are considered as "statistically significant" (*cf.* Rounsefell and Dahlgren 1935). The results of comparing the data in the above manner are given in table IX. The table does not include comparisons which do not show significant differences, nor does it include some of the more obviously significant differences between material

from southern and northern localities. Although more precise comparisons of the data by the "Analysis of Variance" which would take into consideration variation between age groups, between means of samples and between localities are desirable, they are not feasible with the data on hand.

From table IX it may be seen that several year classes of point Grey herring differ very significantly in mean vertebral count from corresponding year classes in those of Saltspring island. For example, the difference of 0.414 vertebrae between the means of the 1929 year class in the two localities (52.191 and 51.777 respectively) is 9.9 times its own standard error. Although the Saltspring island samples were taken by purse seines and those of point Grey by gill nets, the differences between the vertebral data are too great to be accounted for solely by differences in method of capture (p. ~~106~~ 127). Moreover, similar differences of high statistical significance are obtained on comparing the point Grey data with that of gill-netted samples from Nanoose bay, Departure bay and, to a lesser extent, Pender harbour. Although the Saltspring island data do not differ significantly from those of either Departure bay or Nanoose bay, a comparison of the means of the 1932 year class indicates that it is different from that of Granite bay.

The results suggest that, in the strait of Georgia, the runs to Saltspring island, point Grey and Granite bay tend to form local populations. Herring from Departure bay and Nanoose bay may or may not be part of the Saltspring island population. Although the Pender harbour fish do not appear to belong to the point Grey runs, their exact status cannot be determined from the present data.

A difference in the 1929 year class which approaches statistical significance indicates the essential isolation of Saltspring island fish from those of Barkley sound. A significant difference between means of the same year class segregates the Saltspring island run from that to Quatsino sound. These results strongly indicate lack of extensive intermingling between fish from the strait of Georgia and those from the west coast of Vancouver island.

Comparisons of the vertebral data of certain year classes in Barkley sound, Sydney inlet, Nootka sound, Kyuquot sound and Quatsino sound with the same year classes in Bella Bella and Jap inlet show that intermingling is limited or absent between herring from the west coast of Vancouver island and those from the north shore of the province. Lack of extensive intermingling along the west coast of the island is also shown by significant differences between the means of the 1927 year class in Barkley sound and Quatsino sound, and the 1928 year class in Sydney inlet and Kyuquot sound.

Among localities along the north coast, the essential isolation of the Bella Bella herring from those of both Jap inlet and Pearl harbour is indicated by comparisons of the 1929 and 1927 year classes. However, no significant differences in vertebral data were found between material from Jap inlet, Butler cove, Pearl harbour, Prince Rupert harbour and Skidegate inlet.

In comparing the vertebral material in closely-situated localities, in many cases only one out of the several year classes which may be available shows a difference of, or approaching statistical significance. An example of this is given

in the comparison of year classes 1926 to 1932 at Saltspring island and in Barkley sound (table III). Of the seven comparisons, only one, that of the 1929 year class, shows a significant difference at a probability of less than 0.01. Cases such as this are to be expected, as temperature conditions as the time of development of the vertebral column in the two localities (situated at approximately the same latitude) may be similar in several years and different in but one. It might be argued that this difference proves the segregation of but one year class and not of the whole population. This criticism is valid if the results for the year class in either locality are based on one season only. In this particular case, the 1929 year class was sampled in both localities in four corresponding seasons at ages III to VI. The following mean counts were obtained in these seasons:

	1931-32 III	1932-33 IV	1933-34 V	1934-35 VI
Saltspring island....	(239) 51.741	(373) 51.783	(64) 51.953	(45) 51.667
Barkley sound.....	(45) 51.822	(172) 51.861	(53) 51.981	(17) 52.294

Although the means tend to increase with age, those of Barkley sound are consistently higher than those of Saltspring island. Although the difference in mean vertebral count each season is small and not statistically significant, its persistence is added evidence of the segregation of the two runs over a period of four years.

Results similar to the above were obtained in every case in which a significant difference between the grand mean vertebral counts of the same year class in two localities was found and in which data for two or more seasons were available for comparison. Hence, although significant differences between the means of one year class are not conclusive, they are strongly indicative of the lack of intermingling of the two populations as a whole.

Abdominal and Caudal Vertebral Count

As shown by the following mean values for counts made in 1932-33 in localities ranging from Barkley sound in the south to Pearl harbour in the north, the abdominal rather than the caudal segment of the backbone varies between localities and reflects the increase in vertebral count with latitude:

Locality	Mean abdominal count	Mean caudal count	Mean total count
Barkley sound.....	23.17	28.68	51.85
Sydney inlet.....	23.16	28.70	51.86
Nootka sound.....	23.23	28.72	51.95
Kyuquot sound.....	23.18	28.75	51.93
Quatsino sound.....	23.29	28.68	51.97
Bella Bella.....	23.44	28.64	52.08
Jap inlet.....	23.63	28.60	52.23
Pearl harbour.....	23.61	28.64	52.25

Although the abdominal count might be used as a racial character, the complete analysis of the data and the comparisons between localities was not attempted,

as it would be largely a duplication of the work which has already been done on total vertebral count.

The abdominal vertebral count, however, shows a significant and constant difference between Saltspring island and Barkley sound herring, which is not apparent from a consideration of the total count. Comparisons of the means in four corresponding seasons (table X) show that in each season the abdominal count has averaged higher in Barkley sound than in Saltspring island. Even without detailed analysis of the data, the constancy of this difference is evidence that the two populations do not intermingle to any great extent. In the four seasons, the differences were respectively 1.3, 3.0, 3.4 and 4.8 times their own standard errors, showing that in three at least they were unlikely to have been the result of chance.

Table X.--Giving the abdominal vertebral counts for four seasons in Saltspring island and Barkley sound samples

Locality	Season	Number of fish with counts of 19	20	21	22	23	24	25	26	27	Total No.	Mean	$S(x-\bar{x})^2$
Saltspring island	1931-32	-	-	4	104	288	141	24	3	1	565	23.159	385.664
Saltspring island	1932-33	1	-	19	187	446	205	30	2	-	890	23.047	620.018
Saltspring island	1933-34	-	1	4	137	273	114	11	-	-	540	22.978	319.733
Saltspring island	1934-35	-	-	15	180	380	149	22	2	-	748	22.985	494.830
Barkley sound	1931-32	-	-	-	25	63	48	7	-	-	143	23.259	91.427
Barkley sound	1932-33	-	1	5	152	388	219	37	2	-	804	23.167	543.767
Barkley sound	1933-34	-	-	7	136	385	194	25	-	-	747	23.126	446.171
Barkley sound	1934-35	-	-	4	117	426	199	28	2	-	776	23.175	438.165

Similar results were obtained on comparing the count of the Saltspring island material with that of other localities on the west coast of Vancouver island in the four seasons. Only in one case in one season was the count in the former locality higher. Abdominal vertebral counts therefore furnish evidence for the isolation of the Saltspring island run from that of Barkley sound and also from those of other localities on the west coast of Vancouver island.

Keeled Scale Count

Mean keeled scale counts for localities ranging from Barkley sound in the south to Pearl harbour in the north are given in table XI. In all seasons, the counts in northern localities average lower than those in southern localities, suggesting that mean keeled scale count tends to decrease with increase in latitude. Although a regular decrease with latitude in localities on the west coast of Vancouver island is found only in 1931-32, the mean count at Quatsino sound is lower than that in localities to the south in both 1932-33 and 1933-34, the only two seasons for which data are available. That the low averages in northern localities are not caused by personal error is evinced by the 1933-34 counts which were made by a different investigator (Dr. J. L. Hart). For the season 1934-35, counts are available from Barkley sound (11.97), Prince Rupert harbour (11.71) and Skidegate inlet (12.12). Herring from the latter locality, situated on the east coast of the Queen Charlotte islands, have the highest mean value which has been encountered in this northern region. The high value does not conform with the general gradation with latitude.

The differences in mean count between Barkley sound and Pearl harbour in 1931-32 and 1932-33, between Barkley sound and Butler cove in 1933-34, and between Barkley sound and Prince Rupert harbour in 1934-35 of 0.25, 0.25, 0.24 and 0.24 keeled scales were found to be statistically significant being 3.0, 5.0, 4.2 and 3.2 times their own standard errors (0.082, 0.050, 0.057 and 0.074) respectively.

Table XI.--Showing mean keeled scale counts with their standard errors from various localities in British Columbia

Locality	Approximate latitude	1931-32		1932-33		1933-34	
		Mean	S.E.	Mean	S.E.	Mean	S.E.
Barkley sound	48° 55'	12.08	0.063	12.11	0.024	11.99	0.026
Sydney inlet	49° 25'	12.04	0.035	12.12	0.034	12.08	0.048
Nootka sound	49° 42'	12.03	0.045	12.13	0.037	11.97	0.043
Kyuquot sound	50° 6'	12.01	0.039	12.13	0.036	11.98	0.060
Quatsino sound	50° 29'	--	--	11.95	0.053	11.91	0.054
Bella Bella	52° 15'	--	--	11.88	0.039	--	--
Jap inlet	54° 3'	11.87	0.051	11.83	0.043	11.78	0.050
Butler cove	54° 5'	--	--	--	--	11.75	0.053
Pearl harbour	54° 32'	11.83	0.051	11.86	0.044	--	--

The general gradation in keeled scale count with latitude is additional evidence of but a limited degree of intermingling in a northward or southward direction along the coast. It may be noted that Hessle (1925) found a similar gradation in the autumn spawning herring along the Baltic coast of Sweden. However, in these Baltic herring, the vertebral count did not increase regularly with decrease in keeled scale count from south to north as in the British Columbia herring. Hessle believes that the keeled scale gradation is correlated with the decreasing salinity from south to north in the Baltic sea, but he also points out, as Johansen (1924) has stated, that temperature may have some influence upon the number of keeled scales.

Although some of the differences between the mean keeled scale count of closely-situated localities were found to be significant, similar differences also occurred between different year classes in one locality. Detailed analyses of the data and comparisons of corresponding year classes in the various localities were not attempted, however, because of the uncertainty regarding the absolute accuracy of the count (p. ~~97~~ 112).

Pectoral Fin-ray Count

Pectoral fin-ray counts were made on herring from all localities from which samples were available in 1932-33. The number of rays in both fins were recorded, although a high degree of correlation existed between the two. Occasionally abnormalities were encountered but these were not included in the results. Individual counts varied from 14 to 20 fin-rays with 17 and 18 the most frequently occurring numbers. Mean counts in localities extending from Barkley sound to Pearl harbour were as follows: 17.55, 17.60, 17.56, 17.60, 17.63, 17.68, 17.62, and 17.63. The Saltspring island data yielded a mean count of 17.64. It may be seen that there is no uniform variation with latitude and that there are no great differences between either adjacent or distant localities.

Schnakenbeck (1927) considers that, in the Atlantic herring, the pectoral fin-ray count is a valuable racial character and records means of 16.56 and 16.82 (33.12 and 33.63 for both fins), which distinguish the Bank from the West channel herring. Although there is a difference of about one ray between the mean counts of the Atlantic and Pacific herring, this character does not appear to vary significantly among herring from different localities in British Columbia.

Proportions of the Sexes

As, on the average, females are larger than males, and as the gill nets select certain sizes, purse-seined material was used to ascertain whether there were characteristic local differences in sex ratio. Such differences were found to exist between the strait of Georgia and the west coast of Vancouver island, as illustrated by the following percentages for each sex, the number of fish in each sample being given in brackets:

	Saltspring island		Barkley sound	
Season	Males	Females	Males	Females
1929-30	(389) 52.4	(354) 47.6	(395) 44.6	(491) 55.4
1930-31	(360) 57.2	(270) 42.8	(111) 45.9	(131) 54.1
1931-32	(422) 54.9	(346) 45.1	(321) 43.3	(421) 56.7
1932-33	(490) 53.3	(429) 46.7	(403) 49.1	(417) 50.9
1933-34	(291) 51.1	(279) 48.9	(358) 46.5	(412) 53.5
1934-35	(404) 51.4	(382) 48.6	(386) 48.2	(414) 51.8

These figures demonstrate a consistent difference for six seasons between the two places, males being more numerous at Saltspring island and females in Barkley sound, which indicates fairly conclusively that the populations are discrete.

Material from the east coast of Vancouver island for the period 1915-16 to 1925-26 (collected by Dr. C. McLean Fraser, University of British Columbia) showed that males did not predominate every season in the strait of Georgia. Varying proportions of the different age groups being a possible explanation, the average sex ratio of each group for fifteen seasons was calculated, with the following result:

Age	Males	Females
III	(1973) 56.5	(1522) 43.5
IV	(1367) 48.6	(1446) 51.4
V	(516) 46.1	(603) 53.9
VI	(189) 44.2	(239) 55.8

These figures show a gradual change from a predominance of males in the third year to one of females in the sixth year, perhaps due to males maturing and joining the adult schools at an earlier age than the females, as well as dying at an earlier age (of six in their ninth year, five were females).

The average sex ratio of the same age groups for a six-year period in material from the outer coast (Barkley sound), shows the females dominant throughout, but least so in the third year, and there fails to be a gradual change in the ratio. The figures are as follows:

Age	Males	Females
III	(1048) 48.3	(1122) 51.7
IV	(455) 41.3	(646) 58.7
V	(166) 46.2	(193) 53.8
VI	(61) 43.9	(78) 56.1

That the two localities differ significantly in sex ratio is shown by comparing them for the most numerous age group (III). Taking the percentage of males, the difference (8.2) is 4.3 times its standard error (1.91, for method see Tippett 1931, p. 57) and hence significant.

Rate of Growth in Length

Differences in growth rate are indicated by constant differences in either the mean length, the median length, or the length frequency distribution at each age and sex (as shown in tables XII and XIV, females tend to grow at a faster

Table III.--Giving the mean lengths at each age for gill-netted material from the strait of Georgia

Locality	Season	Mean length at age			
		III	IV	V	VI
Males					
Point Grey	1932-33	(13) 191.3	(102) 201.5	(49) 209.4	(8) 218.4
Departure bay	1932-33	--	(11) 208.0	(20) 212.3	(14) 217.8
Point Grey	1933-34	(19) 192.7	(51) 204.2	(90) 211.0	(16) 214.4
Pender harbour	1933-34	(10) 190.4	(23) 200.3	(8) 206.0	(5) 214.4
Point Grey	1934-35	(26) 193.7	(67) 201.0	(56) 212.5	(37) 217.9
Pender harbour	1934-35	(9) 185.3	(27) 194.9	(6) 198.8	--
Nanoose bay	1934-35	--	(35) 207.6	(33) 210.9	(38) 215.1
Females					
Point Grey	1932-33	(10) 191.0	(107) 204.0	(53) 214.0	(15) 217.8
Departure bay	1932-33	--	(51) 207.1	(38) 213.1	(17) 220.7
Point Grey	1933-34	(15) 190.3	(82) 206.6	(90) 213.0	(35) 216.9
Pender harbour	1933-34	(10) 193.6	(14) 200.1	(10) 210.9	(5) 215.2
Point Grey	1934-35	(26) 196.4	(62) 203.7	(46) 215.5	(41) 221.0
Pender harbour	1934-35	(5) 188.2	(24) 194.7	(8) 205.0	(4) 214.8
Nanoose bay	1934-35	(6) 198.5	(52) 206.9	(45) 214.2	(48) 216.8

rate than males) of samples comparable in respect to method and time of capture and condition of preservation. As the majority of the samples were taken by purse seines during the period of retarded growth and were measured while fresh, they may be used in comparative growth studies. Reference will be made to those which are not strictly comparable in discussing the results.

Samples from the gill net fisheries were compared with each other to determine whether differences in growth rate were present as approximately the same size of mesh (2½-inch or 6 cm. stretched measure) was used in all localities. From the results (table XII) it may be seen that there is no clear indication of a difference in growth rate between late summer herring from point Grey and late winter herring from Departure and Nanoose bays when the difference in time of capture is taken into consideration. On the other hand, during the two seasons for which data are available, a distinctly slower growth rate for the Pender

harbour autumn herring as compared with those from point Grey is shown clearly. This indicates that these two runs form populations which are distinct from each other.

On the average, the mean lengths of purse-seined herring of each age and sex were found to be larger in Barkley sound than at Saltspring island. This tendency is illustrated by the following unweighted means of the average lengths in six consecutive seasons (1929-30 to 1934-35 inclusive) in each locality:

	III	IV	V	VI
		Males		
Saltspring island....	181.8	195.0	202.8	211.2
Barkley sound.....	183.1	197.0	205.2	215.1
		Females		
Saltspring island....	183.6	196.8	205.1	213.1
Barkley sound.....	185.6	198.5	205.5	217.2

To test this difference further, the median (which is not influenced unduly by extreme variations, some of which may result from errors in age determination) was calculated for female fish at age IV in the two localities. In table XIII the

Table XIII.--Comparing the median lengths of female fish in their fourth year in Saltspring island and Barkley sound material

Season	Saltspring island				Barkley sound				M_2-M_1	$\frac{M_2-M_1}{S.E._D}$
	M_1	Q_1	Q_2	N	M_2	Q_1	Q_2	N		
1929-30	197.6	194.2	201.6	76	194.3	188.7	199.3	87	-3.3	3.1
1930-31	194.5	189.7	199.9	86	195.5	190.6	203.4	59	+1.0	0.7
1931-32	193.7	188.2	198.4	115	196.7	192.6	202.4	123	+3.0	3.1
1932-33	194.6	189.3	200.1	184	195.4	191.0	200.2	104	+0.8	0.9
1933-34	193.7	189.7	199.5	48	198.0	194.2	203.1	75	+4.3	3.3
1934-35	197.1	192.5	202.4	143	198.8	193.4	203.0	176	+1.7	2.1

medians and their lower and upper quartiles (Q_1 and Q_2) are given, and the significance of their differences is appraised by dividing by the standard errors as calculated from the semi-interquartile range. In five of the six seasons, the median lengths were larger in Barkley sound than at Saltspring island and in three of the five seasons the difference was significant according to the rough test. In one season, however, the median length in the former was significantly smaller showing that only on the average is the growth more rapid. However, it is to be expected that the growth increment, and therefore the mean or median length at any age will be influenced by annual fluctuations in food conditions, and these fluctuations are not necessarily in the same direction in both localities.

To determine whether the difference in growth rate is present at the end of the first year, the length (l_1) of the fish at the time of formation of the first annulus was calculated from scale tracings, using a machine similar to that described by Lea (1910). In the following results for fish taken during 1932-33 at Saltspring island and in three localities on the west coast of Vancouver island, the data are segregated according to the age of the fish from which the calculations were made because of the possible influence of Lee's "phenomenon" (Lee 1912):

	III	IV
Saltspring island	(31) 79.9	(47) 74.0
Barkley sound	(30) 82.5	(35) 81.9
Nootka sound	(24) 81.9	(21) 85.3
Kyuquot sound	(19) 81.3	(18) 86.9

The smaller growth increment of the Saltspring island fish during the first year of life is evident in both series of comparisons.

Table XIV.--Giving the average length at each age and sex for material from various localities in the season 1932-33

Age	Saltspring island		Barkley sound		Bella Bella*		Jap inlet*	
	male	female	male	female	male	female	male	female
III	(178)179.4	(129)183.3	(199)177.9	(191)181.3	(2)177.0	(7)179.5	(4)172.9	(3)173.1
IV	(202)194.9	(184)196.2	(74)197.7	(104)197.1	(52)191.4	(67)194.5	(65)183.6	(92)185.6
V	(43)203.4	(49)208.6	(56)205.8	(63)205.2	(26)195.7	(33)197.5	(17)195.8	(24)196.6
VI	(12)209.3	(6)211.7	(28)214.5	(21)216.4	(39)201.7	(57)204.6	(12)199.3	(17)199.0

* results corrected for shrinkage due to preservation in salt.

Data given in table XIV indicate that there are differences in rate of growth between herring in the vicinity of Vancouver island and those in the northern localities. It may be seen that the mean lengths of both sexes at each

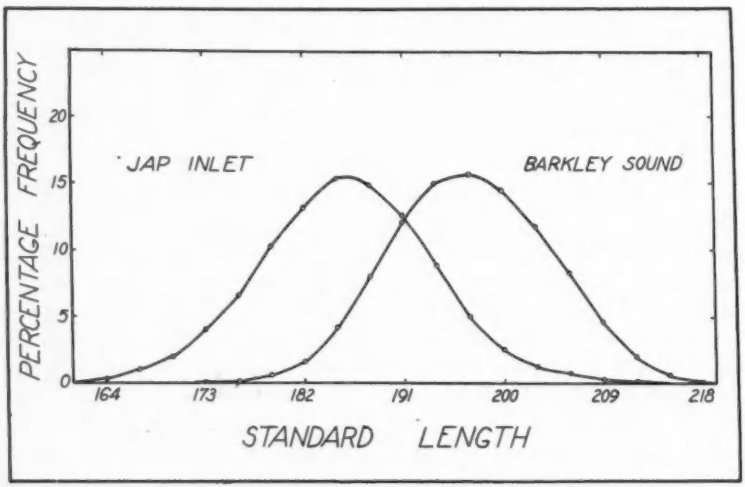

FIGURE 4.—Comparing length frequency distributions of female fish in their fourth year at Barkley sound and Jap inlet.

age are smaller at Bella Bella than at either Saltspring island or Barkley sound. At Jap inlet, farther to the north than Bella Bella, the rate of growth appears to be still slower. In this locality, fish in their fifth year have a mean length which is similar to that of fish in their fourth year in southern localities. This marked difference in growth is illustrated further in figure 4 where the length frequency distributions (in three-millimetre groups smoothed twice by a running average

of three) of females at age IV in Barkley sound and Jap inlet are plotted. Statistical tests have not been applied to the above data because of the approximate nature of the length adjustment in salted fish. However, recent measurements of fresh herring from Klemtu (near Bella Bella) verify the above conclusions concerning the slower growth in northern localities (Tester 1936).

Head Length

Rounsefell (1930) has shown that, in the Alaskan herring, there is a gradual decrease in the mean percentage head length with increase in body length. This same relationship is present in the British Columbia herring as is shown by the following data for 1932-33:

Standard length	Saltspring island	Barkley sound
170	(30) 23.70	(54) 23.70
175	(58) 23.79	(85) 23.62
180	(76) 23.71	(80) 23.43
185	(110) 23.54	(96) 23.36
190	(145) 23.41	(88) 23.40
195	(145) 23.25	(101) 23.26
200	(131) 23.19	(84) 23.00
205	(89) 23.08	(68) 23.04
210	(56) 22.95	(56) 22.83
215	(24) 22.94	(27) 22.87

To compare percentage head lengths in different localities graphically, Rounsefell smoothed his results mathematically (for method see Rounsefell 1930, p. 268) and obtained curves such as those shown for the above data in figure 5A. He considered variation with condition or fatness, but not with sex and age. These sources of variation may invalidate comparisons between localities.

The following results, based on fish in their fourth year in all purse-seined material (excluding salted samples) taken in 1932-33, show that there is no great difference in percentage head length between the sexes:

Standard length	Males	Females
180	(19) 23.87	(12) 23.66
185	(34) 23.45	(23) 23.65
190	(75) 23.42	(73) 23.40
195	(123) 23.20	(136) 23.29
200	(119) 23.09	(140) 23.07
205	(66) 22.90	(106) 22.87
210	(24) 22.84	(33) 22.81

In five of the seven groups the mean is slightly higher in the males (a tendency noted by Thompson 1917), but the difference, if real, is not sufficiently large to warrant segregation of the sexes in comparisons.

To determine whether there was any variation with age, the mean percentage head lengths at corresponding body-length groups were compared for fish of ages III to VI (1932-33 data given in table XV and figure 5B). In the figure the four curves are distinct from each other and show that, for a given

standard length, percentage head length increases regularly with age. Thus fish of 195 mm. at ages III to VI have mean head lengths of 23.02, 23.25, 23.44 and 23.48 per cent, respectively. Similar results were obtained in 1933-34 and 1934-35.

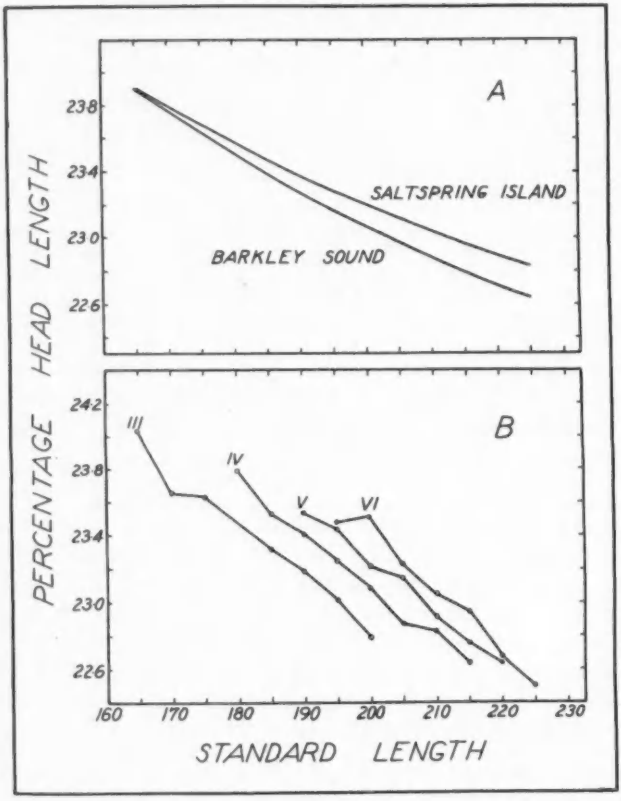

FIGURE 5.—(A) the variation in percentage head length with standard length for Saltspring island and Barkley sound material in 1932-33 by means of smoothed curves, all ages combined; and (B) the variation in percentage head length with standard length and age for material from all localities in southern British Columbia in 1932-33.

The decrease in percentage head length with increase in standard length is undoubtedly the result of a tendency for the head to grow at a slower rate than the body, or "negative heterogony" as defined by Huxley (1932). Thus, as shown in figure 5B, at any given time the larger, fast-growing fish will have a relatively smaller head than the smaller, slow-growing fish. On considering fish of different ages but of the same standard length, a similar phenomenon becomes apparent. A fast-growing fish has a relatively smaller head than a slow-growing *older* fish. Both of these differential tendencies, the latter involving the time element, must be taken into consideration in any attempt to determine

the mathematical relationship between head length and body length for the population.

Table XV.--Giving the average percentage head length in five-millimetre length categories at each age for purse-seined fish from several localities in the season 1932-33

Standard length	In year of age			
	III	IV	V	VI
165	(51) 24.03	--	--	--
170	(102) 23.65	--	--	--
175	(186) 23.63	--	--	--
180	(219) 23.48	(31) 23.79	--	--
185	(269) 23.32	(57) 23.53	--	--
190	(184) 23.19	(148) 23.41	(16) 23.54	--
195	(90) 23.02	(259) 23.25	(45) 23.44	(12) 23.48
200	(43) 22.79	(260) 23.09	(98) 23.22	(19) 23.51
205	--	(171) 22.88	(126) 23.15	(37) 23.23
210	--	(57) 22.83	(136) 22.92	(76) 23.05
215	--	(16) 22.64	(61) 22.76	(65) 22.95
220	--	--	(20) 22.64	(53) 22.66
225	--	--	--	(19) 22.50

The above results show that the position and slope of the smoothed curves used by Rounsefell will be influenced by the average age of fish in each length group. To demonstrate differences in head length between populations comparisons must be confined to fish of one age. When the British Columbia data were analyzed, constant differences in percentage head lengths were found in only one instance,—between the point Grey material and that from other localities in the strait of Georgia. This is illustrated by the following results for IV's in 1933-34 and by additional data contained in table XVI:

Standard length	Point Grey	Pender harbour	Saltspring island
195	(20) 22.16	(9) 23.12	(23) 23.33
200	(24) 21.98	(11) 23.24	(22) 23.02
205	(18) 21.62	(9) 22.68	(10) 22.64
210	(44) 21.32	(3) 22.57	(2) 22.35

Table XVI.--Giving average percentage head lengths at each length and age for point Grey and Saltspring island herring in the season 1934-35

Standard length	Age	Point Grey	Saltspring island
185	III	(5) 23.02	(103) 23.03
190	III	(4) 22.45	(89) 22.80
195	III	(6) 21.48	(42) 22.57
200	III	(7) 21.10	(11) 22.34
195	IV	(17) 22.14	(65) 22.74
200	IV	(21) 22.07	(69) 22.73
205	IV	(18) 21.46	(58) 22.49
210	IV	(11) 21.36	(19) 22.42
200	V	(7) 22.19	(7) 22.77
205	V	(12) 22.01	(15) 22.67
210	V	(10) 21.35	(10) 22.65
215	V	(18) 21.36	(9) 22.42
220	V	(19) 20.86	(4) 22.28
205	VI	(7) 21.64	(8) 22.68
210	VI	(7) 21.26	(9) 22.56
215	VI	(14) 21.12	(13) 22.69
220	VI	(11) 20.99	(8) 22.30
225	VI	(11) 20.33	(4) 21.18

The low averages of the point Grey material are not likely to have been caused by the selectivity of gill nets as the Pender harbour fish were also taken by this method of capture and had high averages. Again, the low averages might be attributed to a difference in fatness or thickness of the fish. As "head length" is a *projected* measurement, a fat thick fish might have a smaller projected head length than a lean thin fish, even though the *actual* head length be the same in both. From other studies, the results of which will be published at a later date, the following condition factors were obtained for herring from point Grey, Pender harbour and Saltspring island respectively in 1933-34: 3.41, 3.68 and 3.39. As the value for the point Grey fish is not excessively high, it may be concluded that the relatively small head lengths of these fish is a distinguishing characteristic of the population.

Length to the Insertion of the Dorsal Fin

When this measurement was expressed as a percentage of standard length there appeared to be no general tendency for the percentages to decrease with increase in body length in a similar manner to head length. This is shown by the following results for the season 1933-34:

Standard length	Saltspring island	Barkley sound
165	(13) 50.74	(11) 50.38
170	(29) 50.81	(22) 50.80
175	(59) 50.49	(39) 50.64
180	(69) 50.47	(67) 50.74
185	(81) 50.60	(113) 50.61
190	(75) 50.62	(99) 50.53
195	(62) 50.48	(94) 50.66
200	(43) 50.28	(61) 50.64
205	(28) 50.85	(43) 50.71
210	(11) 50.82	(33) 50.81

When the data were divided into age groups there was again no tendency for the percentages to vary uniformly with standard length. There also appeared to be no difference between the sexes. However, when the means for both sexes combined over all length groups were considered, in general the percentage length to the dorsal fin insertion tended to increase with age. Thus, the means for the Saltspring island material in 1934-35 at ages III, IV, V and VI were respectively 50.20, 50.32, 50.48 and 50.61. From these results, it may be concluded that the material from the various localities may be compared provided that the data are segregated according to age. Data for the seasons 1932-33, 1933-34 and 1934-35 are available for the more important localities and these are presented in table XVII. Means based on less than 10 specimens are not listed.

From the table it may be seen that point Grey fish have a lower average value at each age in each season than those from other localities in the strait of Georgia. Comparison of the values for point Grey, Pender harbour and Saltspring island in 1933-34 indicates that the difference is not the result of either gill net selectivity or condition factor. It may be concluded, therefore,

that the low percentage to the dorsal insertion is another distinguishing characteristic of the point Grey population. Constant differences also distinguish between samples from Saltspring island and Granite bay, from Saltspring island and Barkley sound (in most comparisons), and from Quatsino sound and other localities on the west coast of Vancouver island. The corrected values for Bella Bella and Jap inlet are higher than those in most southern localities.

Table XVII.--Giving the average percentage length to the insertion of the dorsal fin at each age and season in the various localities

Locality	Season	III	IV	V	VI
Point Grey*	1932-33	(23)49.92	(209)49.90	(102)50.01	(23)50.09
Point Grey*	1933-34	(34)49.93	(133)49.90	(180)49.95	(51)50.01
Point Grey*	1934-35	(29)49.53	(87)49.93	(84)50.00	(69)50.15
Pender harbour*	1933-34	(20)50.34	(37)50.49	(18)50.69	(10)50.53
Pender harbour*	1934-35	(14)50.53	(51)50.70	(14)50.89	--
Granite bay	1933-34	(63)50.99	(13)51.13	(15)50.85	--
Granite bay	1934-35	(70)51.18	(32)51.49	--	--
Saltspring island	1932-33	(304)50.47	(370)50.48	(90)50.52	(18)50.51
Saltspring island	1933-34	(316)50.49	(92)50.55	(66)50.90	--
Saltspring island	1934-35	(336)50.20	(283)50.32	(54)50.48	(47)50.61
Barkley sound	1932-33	(389)50.60	(176)50.67	(119)50.78	(49)50.83
Barkley sound	1933-34	(394)50.62	(141)50.53	(56)50.88	(47)50.82
Barkley sound	1934-35	(304)50.62	(280)50.68	(39)50.74	(17)50.88
Sydney inlet	1932-33	(120)50.40	(129)50.46	(108)50.87	(75)50.75
Nootka sound	1932-33	(191)50.41	(94)50.73	(47)50.88	(24)50.89
Nootka sound	1933-34	(186)50.89	(35)50.58	(20)50.61	--
Kyuquot sound	1932-33	(139)50.57	(146)50.80	(56)50.89	(20)50.94
Kyuquot sound	1933-34	(105)50.68	(17)50.58	--	--
Quatsino sound	1932-33	--	(47)51.14	(58)51.47	(80)51.36
Quatsino sound	1933-34	(76)51.18	(18)51.36	(38)51.83	(37)51.70
Quatsino sound	1934-35	(114)51.66	(56)51.31	(10)51.33	(17)51.70
Bella Bella**	1932-33	--	(119)50.43	(59)50.85	(96)50.69
Bella Bella**	1934-35	(40)50.81	(108)51.20	--	--
Jap inlet**	1932-33	--	(157)51.01	(41)51.23	(29)51.24
Jap inlet**	1933-34	(96)50.96	(31)50.90	(82)51.00	(20)51.21
Jap inlet**	1934-35	(66)51.31	(73)51.42	--	(13)51.53

* gill-netted fish.
**corrected for shrinkage due to preservation in salt.

The constancy of most of the above differences is regarded as strong evidence of their statistical significance. To test some of these further, however, the individual averages were compared in the usual manner. A difference of 0.58 per cent between the means of point Grey and Saltspring island herring in 1932-33 at age IV was 7.5 times its own standard error (0.077) and was therefore very significant. Other comparisons of the 1934-35 material at age III between Granite bay and Saltspring island, between Barkley sound and Saltspring island, and between Barkley sound and Quatsino sound, revealed that the differences of 0.98, 0.13 and 1.04 per cent were 10.1, 2.0 and 11.4 times their own standard errors (0.097, 0.065 and 0.091) respectively.

The presence of constant and significant differences in percentage length to the insertion of the dorsal fin between herring from several different localities therefore adds to the evidence already accumulated that intermingling between the runs to these localities is limited.

Age Composition

Although age composition is not usually regarded as a racial character, it is shown elsewhere (Tester unpub.) that the diversity in age composition encountered in the various runs in the same season, and the "following through" of the variation in the strengths of successive year classes from year to year, together strengthen the conclusions arrived at in preceding sections regarding the lack of extensive intermingling.

In addition, age composition indicates that some of the runs which were not segregated by the analyses of racial characters, tend to form local populations. The Sydney inlet run was characterized by a dominance of the 1928 year class as IV's and V's in 1931-32 and 1932-33. This, and other features of age composition, were very different from that of Barkley sound to the south and Nootka sound to the north, indicating the essential isolation of the Sydney inlet population. Evidence from age composition will also be presented to indicate that, among northern localities, the Skidegate inlet run forms a local population. In this locality in 1934-35 the 1928 year class was very strongly dominant at age VII, whereas it was but poorly represented in all other samples from Hecate strait. Certain slight differences in age composition were also present in 1931-32 and 1932-33 between the runs to Pearl harbour and Jap inlet.

DISCUSSION

A consideration of total vertebral count, abdominal vertebral count, keeled scale count, sex ratio, rate of growth, head length, and length to the insertion of the dorsal fin has revealed the presence of certain regular gradations with latitude and the presence of certain constant and significant differences in one or several of these characters between fish of many of the localities which have been investigated. On this basis, it has been concluded that intermingling of the stock as a whole is limited and that the herring in several areas comprise essentially discrete units or local populations. As conclusive evidence to the contrary has not been revealed by the application of tests of heterogeneity to vertebral data, it has been assumed also that but one population is present in each locality. These conclusions will now be considered in greater detail.

From the presence of constant and significant differences in racial characters between two populations, it may be assumed that free intermingling between the members of the two populations does not take place. If this were not the case, differences in structure caused by local differences in environment or by hereditary tendencies would be quickly obliterated. However, it cannot be concluded that two populations showing such differences are completely isolated from each other, for even when highly significant differences occur, a slight degree of intermingling may still take place.

No attempt has been made to delineate the areas occupied by local populations. This would necessitate more accurate knowledge of the slight extent of mixing which may occur and also more accurate knowledge of the extent of seasonal migration. It is possible that local populations are limited in area by either narrowly-defined boundaries imposed by physiographical or geographical

barriers, or by broadly-defined barriers imposed by the range of migration. For example, along the west coast of Vancouver island it is possible that each sound and inlet has its own distinct population, which is limited in its movements by physical or chemical peculiarities of the water, which are possibly coupled with the geographical contours of the coast. On the other hand, there may be present along the west coast of the island a series of intergrading communities, any one of which is distinct from a similar community beyond the range of migration of each.

As schools of herring are present in abundance on the various fishing and spawning grounds for only a part of the year, some degree of seasonal migration may also be postulated. After spawning in the spring, mature herring would appear to migrate to summer feeding grounds, the locations of most of which are not known with certainty. One is located off point Grey and another probably in the vicinity of Pender harbour in the strait of Georgia. These support the summer and early-fall gill net fisheries in these areas. The evidence from racial analysis shows, however, that these grounds are not those frequented by Saltspring island herring. The summer feeding ground of the mature herring of the latter run is unknown. Fishermen believe that in October, the schools come from the south and gradually move northward as the season progresses. This would suggest that they have come from a feeding ground located in the southern part of the strait of Georgia, in Juan de Fuca strait, or in the open waters of the Pacific ocean off the strait. The summer feeding grounds of herring which spend the winter and spawn in the sounds and inlets on the west coast of Vancouver island are possibly located a few miles off the coast. Fishermen have observed large schools of herring offshore in the summer, and Clemens and Wilby (1933) report the presence of herring in the stomachs of seals which were captured from 15 to 28 miles (21 to 52 km.) offshore during June and July. The meagre information available for herring in northern waters indicates that they usually appear first near Pearl harbour from one to three months prior to spawning and gradually move southward. Therefore, lack of complete knowledge concerning these seasonal movements renders unfeasible any attempt to delineate the areas occupied by local populations.

As sampling is confined to but a portion of the year and to but a portion of the population—the mature fish—it is possible that intermingling may take place at other seasons of the year, possibly on the feeding grounds, or during juvenile stages. If this be true, partial or complete segregation must follow, for some of the differences which have been detected between herring of certain localities are constant from year to year. As the vertebral number of herring is probably fixed at or a short time after hatching, it may be inferred from the studies of the counts of mature fish that extensive mixing of the larvae of the different localities does not occur. The chances of the larvae being carried for great distances and mixed by ocean currents are doubtless reduced by the peculiar spawning habits of the Pacific herring. Studies of the distribution of larvae in certain localities in the strait of Georgia indicate that they are not carried for great distances during the planktonic stage, for larvae from particular spawning grounds have been traced from the time of hatching to that of schooling and

metamorphosis. Possibly within the various localities, the larvae of individual spawnings are mixed to a greater or lesser extent by tidal action.

Failure to demonstrate the existence of significant differences in racial characters between herring of adjacent localities does not necessarily mean that the same population is being sampled in each, although this assumption may be adopted with reservation until proof to the contrary is at hand. Similarly, negative results from tests of heterogeneity do not prove that but one population is present in a given locality, but again this assumption may be adopted as a working hypothesis pending the collection of more extensive data. While the vertebral count is probably the character most suitable for such analyses, the interpretation of the results offers many difficulties. When the large number of distinct spawnings in each locality and the possibility of two or more spawnings on the same spawning ground at different times, and presumably at different temperatures in the same season, are both taken into consideration, it is hard to escape the conclusion that even if extensive sampling still indicated the homogeneity of the vertebral material, essentially it must consist of a mixture of the products of these separate spawnings, any one of which may have a significantly different mean vertebral count from another. Persistent failure to prove heterogeneity would indicate the thorough mixing of these separate units within the area occupied by the local population. If extensive sampling proved the heterogeneity of vertebral material of one year class and age in a locality there are two possible explanations, either that two or more isolated groups or local populations are present, or that the schools themselves differ significantly in vertebral count from each other and must be regarded as separate units. If the latter should prove to be the case, more extensive application of the "Analysis of Variance" may be necessary to segregate local populations.

From the above discussion it will be realized that the term "local population" as used by the present author is more or less synonymous with the term "local form" as defined recently by Lissner (1934) in his discussion of the modern concept of a race. Whether or not the local forms encountered in British Columbia could be grouped into one or more "races" is a matter of conjecture.

Finally it might be noted that the general reliability of conclusions drawn from an analysis and comparison of racial characters has been to a large extent affirmed by tagging experiments on herring which have been conducted in Alaska by Rounsefell and Dahlgren (1935). Their methods, involving the use of magnetic belly tags and an electro-magnetic recovery apparatus, are described in an earlier paper by the same two authors (1933).

SUMMARY AND CONCLUSIONS

An investigation is made of the schools of mature and maturing herring of British Columbia to determine the extent of intermingling and migration of the runs from a consideration of so-called "racial" characters. For this purpose, various counts, measurements, and sex and age determinations are made on numerous samples of herring taken at random from the commercial purse seine and gill net catches and from the spawning schools in many different localities from 1929-30 to 1934-35 inclusive.

Before comparing the means of these characters in the various areas, an

attempt is made to determine their sources of variation within samples from individual localities. It is found that the mean vertebral count of samples varies with year class; that the mean vertebral count of a year class increases with age; that the larger individuals of a year class have a higher vertebral count; that in one locality at least there is a change in sex ratio with age, females becoming more numerous in the older groups; that percentage head length and percentage length to the insertion of the dorsal fin both vary with age and the former also with standard length. Whenever possible, causes of these changes are presented and discussed. They are either taken into consideration or are eliminated when comparisons are made between localities.

A gradation in mean vertebral and keeled scale count is shown to be present within the waters of the province. Whereas the former increases the latter decreases towards the northwest.

Analysis of the vertebral data of one year class gives no conclusive evidence of heterogeneity in each locality. As a working hypothesis, it is assumed that but one population is present in each, but the assumption in the case of the Saltspring island area and those from which but a small number of samples is available must be accepted with caution.

Tests of heterogenity when applied to vertebral data of one year class in one season for all localities show the presence of two or more populations in the waters of the province as a whole. Further analysis reveals the presence of significant differences between samples from the strait of Georgia, the west coast of Vancouver island and the north coast of British Columbia. Within these general areas data from the following localities differ significantly: point Grey and other regions in the strait of Georgia; Saltspring island and Granite bay; Barkley sound and Quatsino sound; Sydney inlet and Kyuquot sound; Bella Bella and Jap inlet—Pearl harbour.

The mean abdominal vertebral count of Barkley sound fish is consistently higher than that of Saltspring island fish, although these two populations did not show similar constant differences in total vertebral count.

Constant differences in sex ratio are found between the herring of Saltspring island and those of Barkley sound and adjacent localities.

The rates of growth of males and females are found to be more rapid in the point Grey herring than in those of Pender harbour. In general, the mean length at each age and sex is larger in Barkley sound than at Saltspring island, although the difference is not consistent at all ages in all years. Calculations of the length at the time of formation of the first annulus also show higher values in the former locality. Growth in areas north of Vancouver island is relatively slow.

The point Grey herring have a smaller percentage head length and a smaller length to the insertion of the dorsal fin than those of all other localities in the strait of Georgia. Differences in the latter character are also found between Saltspring island and Granite bay, between Saltspring island and Barkley sound, and between Quatsino sound and all other localities on the west coast of Vancouver Island.

From a consideration of the evidence summarized above and from additional evidence from age composition, it is concluded that intermingling of the runs

of herring in British Columbia is limited in extent and that the total stock is divided into a number of essentially discrete units or local populations. Differences in one or several characters segregate the populations in the following localities or groups of localities: point Grey; Granite bay; Saltspring island—Departure bay—Nanoose bay; Barkley sound—Sydney inlet; Nootka sound—Kyuquot sound; Quatsino sound; Bella Bella; Jap inlet—Butler cove—Pearl harbour. There are indications from age composition that the Sydney inlet run also forms a local population. Similar evidence indicates the presence of a local population at Skidegate inlet and at Pearl harbour. The status of Prince Rupert harbour, Bella Coola, and Pender harbour herring has not been established, although it is certain that the latter are not part of the point Grey run.

The designation of these runs as local populations does not preclude the possibility of a slight degree of intermingling between adjacent or closely-situated groups. Because of this possibility and also because of incomplete knowledge of the seasonal movements which seem to take place between summer feeding grounds and winter habitats, no attempt is made to define precisely the areas which they occupy. The possibility also exists that further investigation will reveal that any of these populations may be further divisible into two or more separate units.

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The Length and Age Composition of the Herring (*Clupea pallasii*) in the Coastal Waters of British Columbia

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(*Received for publication July 6, 1936*)

ABSTRACT

A general survey is made of the length and age composition of the herring runs as revealed by random samples from the purse seine and gill net fisheries and from the spawning grounds. Considerable diversity in length and age composition between the various schools in one run and between the various runs in the same season is encountered. The incoming year class is found to join the runs of mature fish in force in the third year in southern and in the fourth year in northern waters. Year class variation is less extensive than in Alaskan and European herring and although dominant year classes are encountered they are less pronounced and persist for fewer years in the catches, particularly in the southern waters. However, it is shown that variation is sufficient to induce fluctuations in the catch. Certain trends in length and age composition over a twenty-year period in the major fisheries are found and these are attributed to the effects of the increased intensity of fishing in recent years. Because of the fluctuations in fishing intensity but chiefly because of the large percentage of the catch formed by the incoming year class, the forecasting of length, age and abundance is impractical in the present state of knowledge.

INTRODUCTION

Studies in length and age composition of herring are of value in yielding information on the extent of variation in the relative abundance of the successive year broods or "year classes" of which the runs are composed. In both the European herring fisheries (Hjort 1926; Lea 1930; Hodgson 1929; Ford 1933; etc.) and the Alaskan herring fisheries (Rounsefell 1930; Rounsefell and Dahlgren 1932 and 1935), successive year classes have been found to vary in strength, thereby inducing annual and long-term fluctuations in the abundance of the populations. In both regions, particularly rich or "dominant" year classes have been found to occur at intervals and to form the bulk of the catch for several years. Knowledge of variation in length and age composition may therefore help to explain fluctuations which have occurred in the British Columbia herring (Tester 1935) and may also enable prognostications to be made of future fluctuations in both size and age, and possibly in abundance.

Acknowledgments

The author is greatly indebted for direction and advice to Dr. W. A. Clemens, Director, and to Dr. J. L. Hart, Assistant Biologist, of the Pacific Biological Station, Nanaimo, B.C. To these, and to other members of the staff of the

Station, to Dr. A. G. Huntsman, Department of Biology, University of Toronto, and to Dr. G. A. Rounsefell and Mr. E. H. Dahlgren, U.S. Bureau of Fisheries, Seattle, Washington, many thanks are given for helpful suggestions and for critically reading the manuscript.

Thanks are tendered to Dr. C. McLean Fraser, Department of Zoology, University of British Columbia, for contributing measurements, sex determinations and scales from samples of herring collected from 1915-16 to 1925-26. This material has been invaluable in yielding information on the length and age compositions of the runs in the early years of the fishery.

Assistance in collecting samples and in giving information relative to the fishery by members of the Dominion Department of Fisheries and by members of the fishing industry of this province is gratefully acknowledged. Thanks are also due to the Provincial Department of Fisheries for rendering financial assistance during part of the period of investigation.

Material

Most of the samples on which the results of this paper are based, are the same as those listed and discussed elsewhere (Tester 1937). These were taken at random from catches made by the commercial purse seine and gill net fisheries which are active in the strait of Georgia, on the west coast of Vancouver island, and along the north shore of the province (Tester 1935), or from catches made by means of beach seine, dip net, rake, or jig on the spawning grounds during the seasons from 1929-30 to 1934-35 inclusive. The locations of the more important areas from which samples have been obtained are shown in figure 1.

Table I.—Summary of information relative to samples taken by purse seine in the early years of the herring fishery.

Season	Locality of capture	Number of samples	Total number of fish
1915-16	Strait of Georgia: Departure bay, Cowichan gap	6	780
	Barkley sound	1	511
1916-17	Strait of Georgia: Nanoose bay, Nanaimo harbour, Departure bay	5	596
1917-18	Strait of Georgia: Nanoose bay, Departure bay	4	684
1918-19	Strait of Georgia: Departure bay	3	503
1919-20	Strait of Georgia: Nanaimo harbour, Departure bay	8	449
1921-22	Strait of Georgia: Departure bay	10	597
1922-23	Strait of Georgia: Chemainus bay, Cowichan bay, Departure bay	7	364
1924-25	Strait of Georgia: Swanson channel (?), Departure bay, Nanoose bay	3	391
1925-26	Strait of Georgia: Cowichan bay, Porlier pass, Dodd narrows	6	419

In addition, however, there are available samples collected by Dr. C. McLean Fraser from 1915-16 to 1925-26, and these are listed in table I. Apart

from one large purse-seined sample from Barkley sound in 1915-16, all of these were taken from the purse seine fishery on the southeast coast of Vancouver island. Dr. Fraser gives his assurance that all were taken at random from the

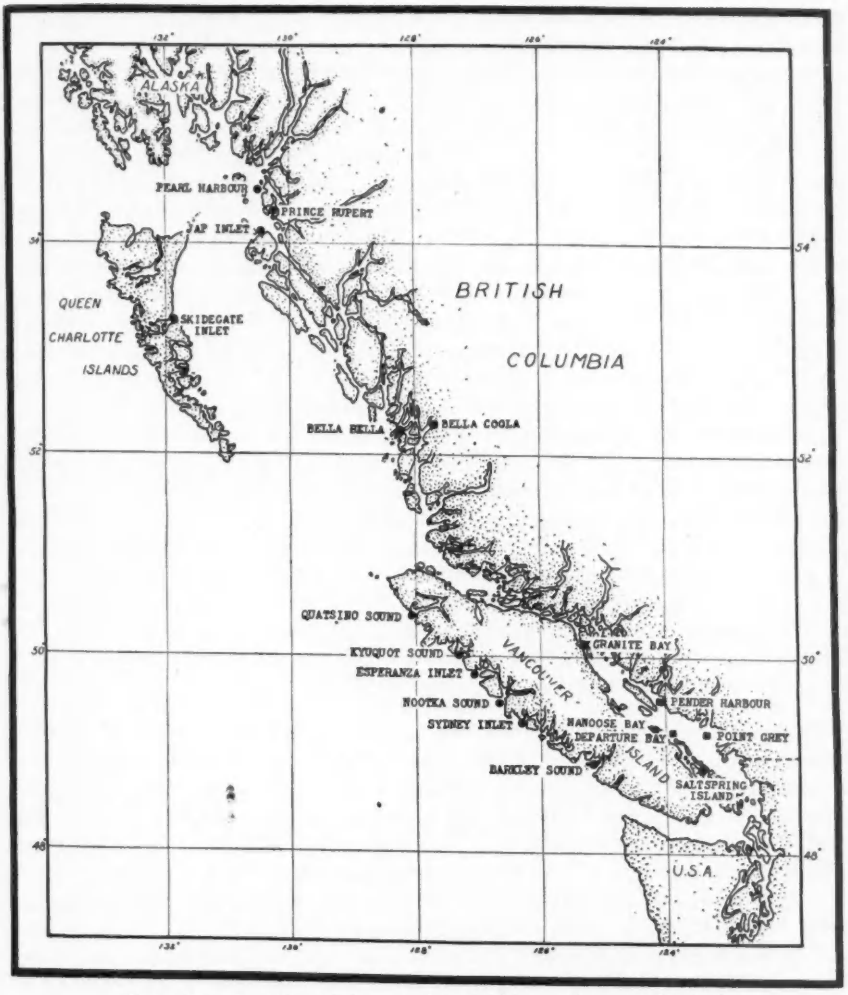

FIGURE 1.—Location of the areas from which samples were obtained.

commercial catches. Individual samples, collected at irregular intervals each season, comprised usually from about 30 to 300 fish.

Corresponding with a southward trend in the scene of fishing activity on the southeast coast of Vancouver island, Dr. Fraser's early samples were taken in the vicinity of Departure bay and Nanaimo and his later samples were collected

farther south, in the vicinity of Saltspring island. Although this slight difference in locality of capture is present, these samples and also those taken from the latter region from 1929-30 to 1934-35 have been grouped together and are discussed under "Saltspring island". This grouping seems justifiable as there has been no evidence to date that the populations in the two closely-situated areas are distinct from each other (Tester 1937).

Methods

In all material collected since 1929, length measurements were made on a specially constructed measuring board similar to that described and illustrated by Rounsefell (1930). Standard length may be defined as the distance in millimetres, as projected on this measuring board, from the tip of the closed lower jaw to the end of the silvery area on the caudal peduncle after the scales have been removed from this region. Length measurements contributed by Dr. Fraser were made usually in millimetres or half-centimetres to the end of the caudal peduncle where it shows opaque as compared with the semi-transparency of the fin-rays. To render the latter comparable with those of the author they were reduced by 2.0 mm., an average correction factor obtained by measuring 50 fish according to both definitions.

Scales were taken from the anterior part of the body below or in front of the dorsal fin. In collections from 1931-32 to 1934-35, they were taken with somewhat greater precision from small areas on both sides of the body at the tip of the flexed pectoral fin whenever possible. Age estimations were made from the scales without reference to the lengths of the fish. Usually from 5 to 15 scales of one fish were mounted in water between two glass slides; their images were projected by means of a Promar apparatus; and the "winter rings" or annuli were counted. Ages were indicated by Roman numerals. For example, a fish whose scales showed two winter rings and three summer bands was considered to be in its third year and was designated by "III".

Reliability of the Age Estimations

Indirect but convincing proof of the reliability of the scale theory of age determination in *Clupea harengus* has been given by Hjort and Lea (1911), by Lea (1911), and again by Hjort and Lea (1914) for the herring of Norway. Similar proof is furnished by the results of Hodgson (1925) for herring from the North sea.

Ages have been determined from the scales of *Clupea pallasii* by Thompson (1917) in British Columbia and by Rounsefell (1930, etc.) in Alaska. The author has found that in British Columbia, as in Alaska (Rounsefell 1930), the new annulus appears first in April but that the exact time of its appearance varies considerably. In agreement with Hodgson (1925), it has been found that the number of fish with scales showing the typical summer edge increases during April, May and June and then decreases, and that the zone of new growth, extending from the annulus to the periphery of the scale, increases in width with advance in season. These results indicate that the phenomena of scale growth in *C. pallasii* are similar to those in *C. harengus* and that the scale theory of age estimation is equally applicable.

As found by Thompson (1917) the scales of herring from southern British Columbia are particularly difficult to interpret. In this region, many have indistinct annuli and these are often complicated by the presence of secondary checks. Also, as pointed out by Rounsefell (1930), in old fish the last few annuli become crowded towards the margin and the first and second annuli are often indistinct. Apart from this latter difficulty, the scales of herring from the northern waters of the province are much more clearly marked and, in this respect, resemble those of Alaska. Whereas in southern waters many fish (5 to 10 per cent) have undecipherable scales, in northern waters the number is much smaller (less than 2 per cent).

Although there is no absolute check on the accuracy of the scale readings reported in this paper, the consistency of the results may be determined by re-reading the scales. One sample of 100 fish taken at random from each of four seasons' collections (Saltspring island fishery) showed from 4 to 11 cases of disagreement in each between the first and second independent determination. Of the 400 fish, the scales of 38 were undecipherable, the ages of 94 were doubtful in both estimations and in 27 of these the second reading disagreed with the first. Assuming these results to be typical of southern waters, 74.0 per cent of the recorded ages may be considered as perfectly reliable and an additional 18.5 per cent as somewhat less reliable. Probably half and possibly all of the remaining 7.5 per cent are in error. Although this inherent error is large it should not detract from the reliability of general conclusions based on age composition, for it was found that the essential features of age distribution were similar in both sets of determinations. In northern waters, where the annuli on scales are much more distinct, the percentage of unreliable age estimations included in the results is considerably less.

RESULTS

School Variation

It has been shown elsewhere (Tester 1937) that the runs of herring to many localities in British Columbia tend to form essentially discrete units, or local populations. Samples from each of these populations may be drawn from one or more of the various shoals or schools of which they are comprised. It is desirable to determine whether a sample of the usual size (100 fish) is representative of the length and age composition of the school from which it was drawn and to what extent these characters vary among different schools in the same locality.

In figure 2 are given the length frequency polygons (five-millimetre class intervals) of successive samples of 100 fish from one beach-seined catch of spawning herring (Horswell point, March 12, 1933). Although the length ploygons differ from each other in shape and in the position of the modes, application of the Chi-square test (Tippett 1931, p. 72) to the data showed that length variation was no greater than would be expected in random sampling from a homogeneous group. When the data of all samples are combined, the length polygon tends to become smooth, and is approximated by the curve (broken line, upper panel) obtained by smoothing the data twice by a running average of three. Curves which also approximate this are obtained on smoothing the data of individual

samples in a similar manner. Figure 2 also shows that the age compositions of individual samples were very similar to each other, all age groups being present in approximately the same proportions throughout. From these results it may be concluded that a random sample of 100 fish gives a fairly reliable estimate of both the length composition (if smoothed) and of the age composition of the catch. However, in virtue of the small number of fish in the youngest (II) and oldest age groups (VII and above) the percentages in these are less reliable than those in the larger groups.

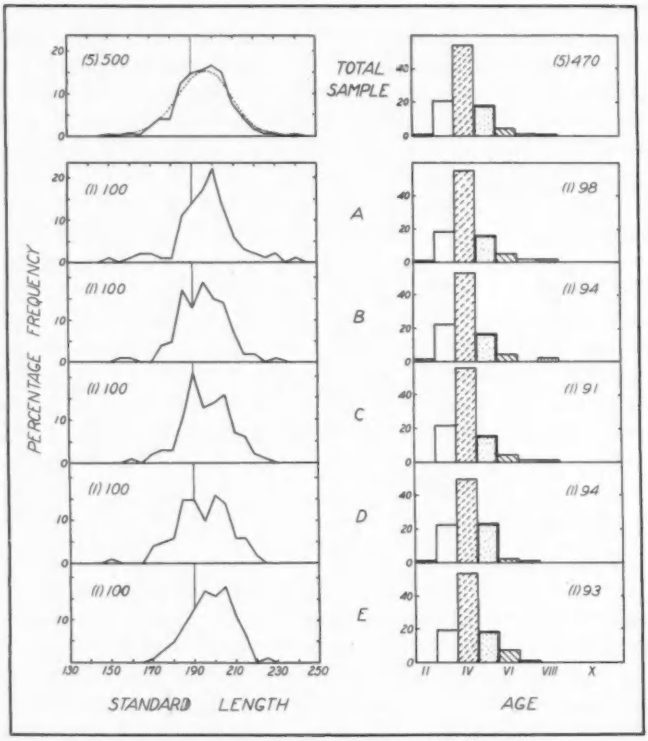

FIGURE 2.—Length and age compositions of five individual samples from the same catch compared with the total sample. In this and following figures the inserted numbers refer to the number of samples (in brackets) and the number of individuals on which each estimate is based.

In figure 3 are shown smoothed length frequency curves and age histograms of samples taken at successive time intervals from the same general locality (Saltspring island, 1932-33). When the Chi-square test was applied to the original length data it was found that of the 36 possible comparisons, 12 were not significantly different, 4 were on the borderline ($P = 0.05$) and 20 were significantly different ($P = 0.01$ or less). Variations in length composition are paralleled by

variations in age composition, the percentages of III's, IV's and V's fluctuating greatly from sample to sample. It is evident without recourse to statistical procedures that many of these differences in age composition are significant (*cf.* figure 2).

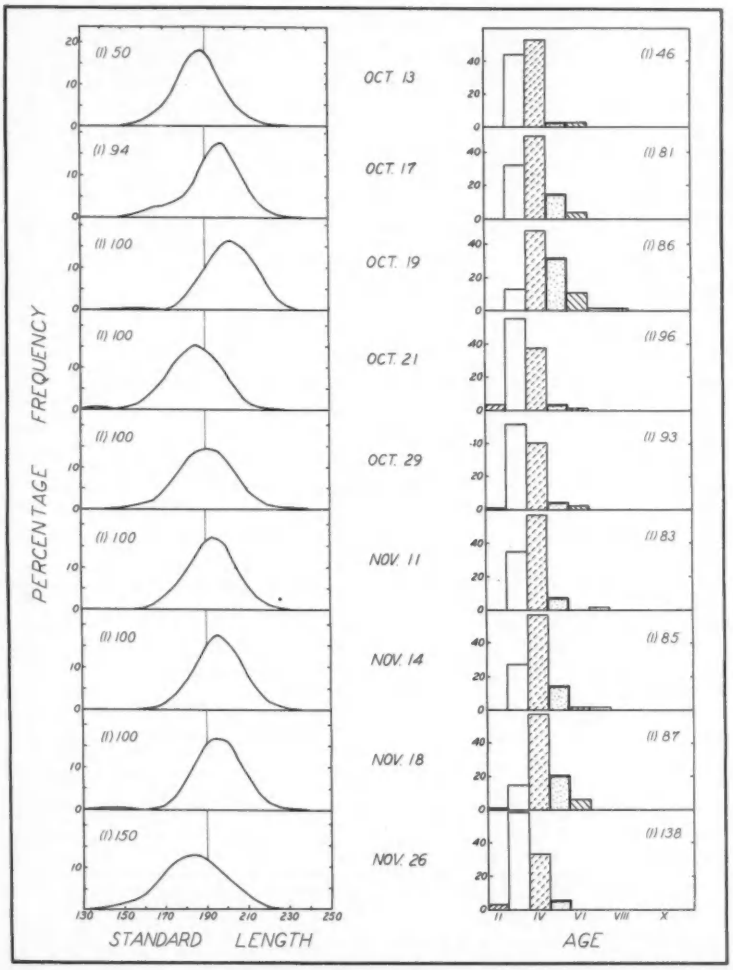

FIGURE 3.—Length and age compositions of individual samples from the Saltspring island fishery in 1932-33.

In several other years, individual samples from both the Saltspring island and Barkley sound populations differed significantly in length and age composition. As these differences between samples and presumably between schools (the selection involved in the use of beach and purse seine is small) are present,

reliable estimates for each population in each year can be obtained only by the examination of several samples. Those based on single large samples must be accepted with caution.

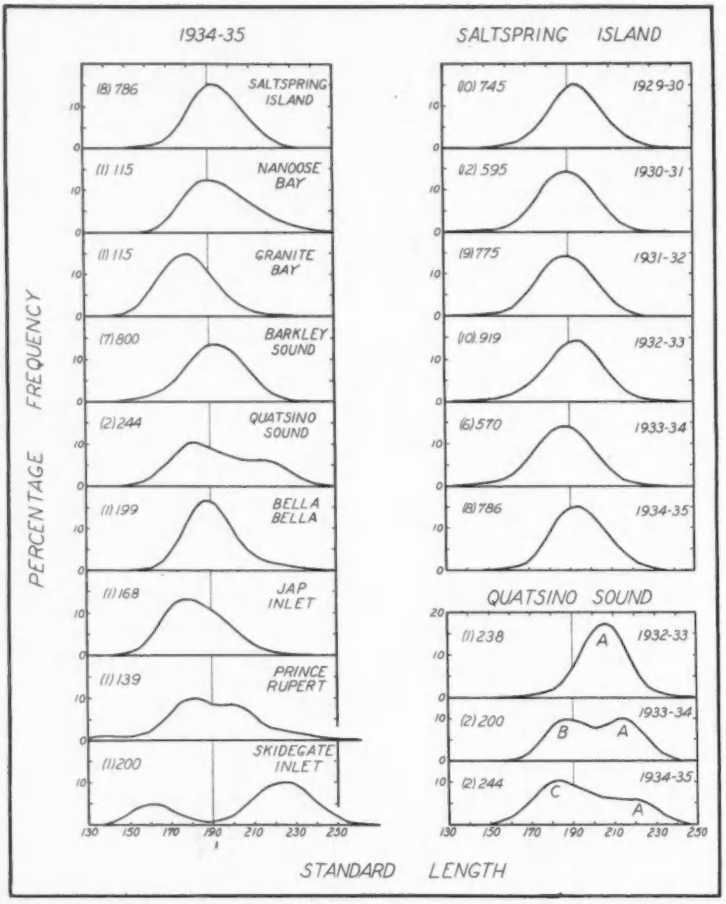

FIGURE 4.—Length composition of herring in various localities and seasons.

Close examination of all the data on hand does not reveal any gradual change in age composition during the fishing season such as that discovered by Lea (1929) in the spawning shoals of Norwegian herring, by Hodgson (1927) in the North sea fishery, and by Ambroz (1931) in the sea of Japan fishery.

VARIATION IN LENGTH

The general features of length composition of the runs are illustrated by the smoothed frequency curves in figure 4. The data for northern localities (Bella

Bella, Jap inlet, Prince Rupert harbour, and Skidegate inlet) have been corrected for shrinkage due to preservation in salt (Tester 1937). The length distributions of gill-netted samples have not been included in the figure.

From the curves for 1934-35 it may be seen that, in general, lengths range from about 140 to 240 mm. but that the spread in length distribution tends to be greater in northern than in southern populations. An outstanding feature of the series is the variation in position and shape of the curves from the different localities in one season. Although some of the distributions are based on single samples, the variation between certain of these is much greater than would be expected from school variation within a population. The majority of the length distributions are unimodal but the position of the mode varies considerably. The curves for Quatsino sound and Prince Rupert harbour in 1934-35 tend to have two modes. That for Skidegate inlet consists of two parts, the first of which is quite distinct from the second. Bimodal length-frequency curves such as these suggest the presence of two or more predominating age groups in the catch.

Annual variation in length composition is illustrated by the frequency distributions for Saltspring island and Quatsino sound. In the former population the curves are essentially similar in shape and differ only slightly in position from year to year over the six-year period. It will be evident from the following section that these slight differences between the curves are related to variations in age composition. The curves from Quatsino sound differ considerably from those of Saltspring island and they also differ from each other in the three years. From the figure, it would seem that a group of fish (A) of large average length was very abundant in 1932-33 and that, although other groups of smaller fish (B and C) entered the fishery in subsequent years, this group continued to predominate to some extent in the catches, growing larger in length each year, and distorting the shape of the frequency curve accordingly.

Variation in Age

The percentage age compositions of samples from various localities throughout the waters of the province are shown in figures 5 to 8. In these the various year classes are indicated for each group of fish at age III. In general, ages range from II to XI, but the bulk of the catch (often over 95 per cent) consists of fish from III to VI inclusive. Herring older than VIII or IX are extremely rare. The oldest encountered was of age XIII (Barkley sound, 1915-16; Skidegate inlet, 1934-35). Comparison of figure 8 with figures 5 to 7 shows that in northern waters there is both a greater spread in ages and a much larger percentage of older fish than in southern waters.

Comparison of samples taken by similar methods of capture in the same season shows a considerable diversity in age composition among the various regions. Thus, in 1932-33, III's predominated (were more numerous than the adjacent younger and older age group) at Barkley sound and Nootka sound; IV's at Saltspring island, Departure bay, Kyuquot sound, and Jap inlet; V's and III's at Sydney inlet; VI's at Quatsino sound; and IV's and VI's at Bella

Bella and Pearl harbour. Similar differences between localities are present in other seasons.

The best illustration of annual variation in age composition in one locality is afforded by the Saltspring island data which are available for 15 of the 20 seasons from 1915-16 to 1934-35, each being represented by several samples and

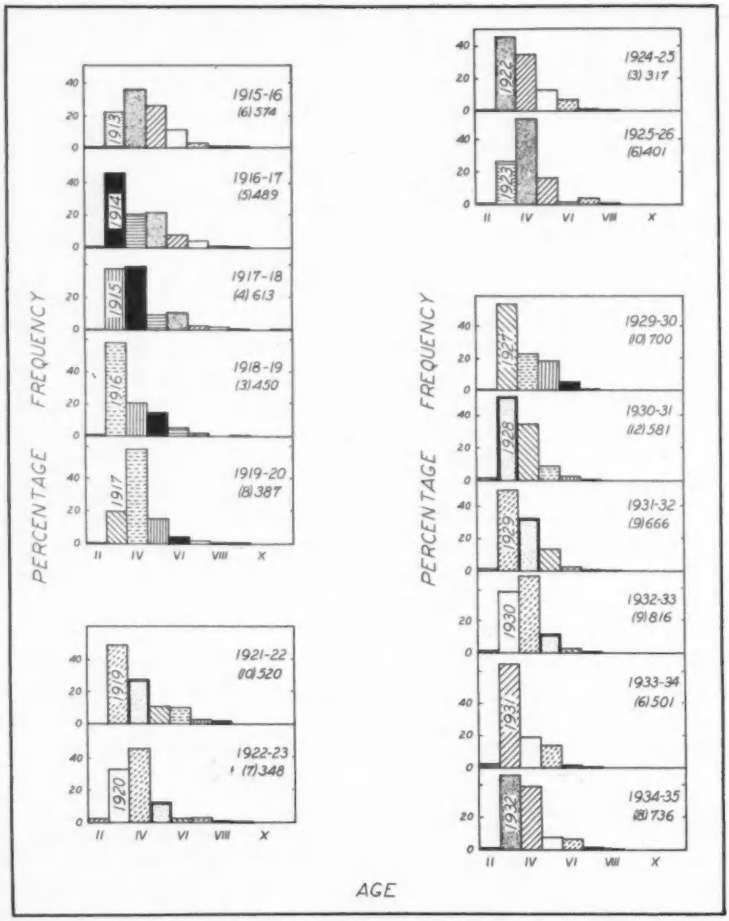

FIGURE 5.—Age composition of herring from the southeast coast of Vancouver island (Saltspring island fishery) from 1915-16 to 1934-35.

several hundred individuals. While there has been considerable variation, only two age groups, the III's and IV's have predominated over all others during the period. A predominance of III's in one year is often, but not invariably, followed by a predominance of IV's in the following year. Thus the following

year classes have "dominated" in the catch for two seasons: 1912, 1914, 1916, 1919, 1922, and 1929. Others may have occurred in the years for which data are not available. One relatively abundant year class (1912) formed a larger percentage of the catch than both the preceding and succeeding year class until age VI (1917-18). Although the 1931 year class, appearing as III's in 1933-34,

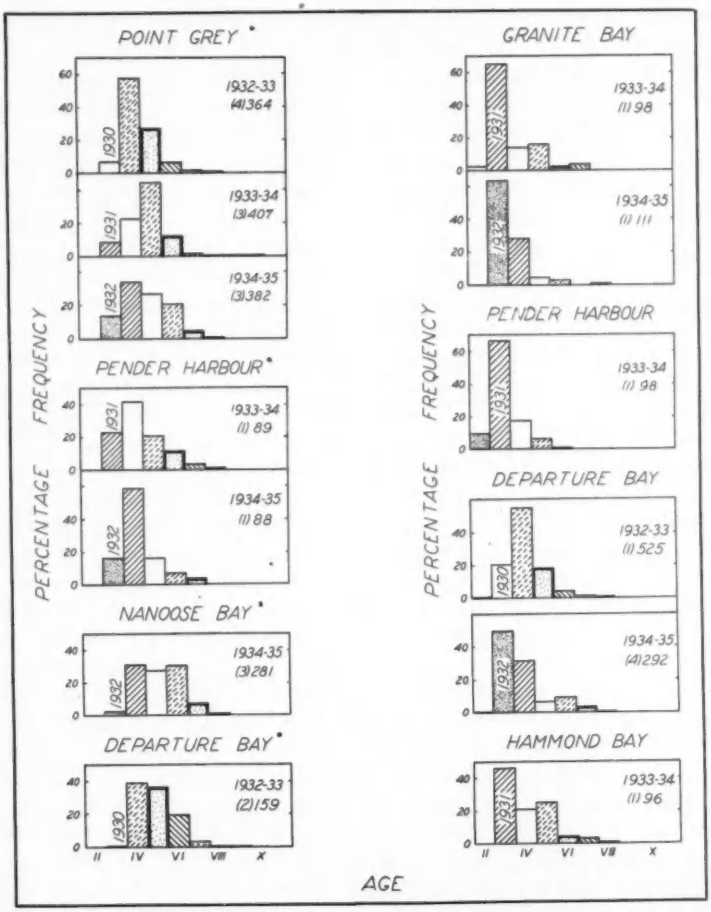

FIGURE 6.—Age composition of herring from localities other than Saltspring island in the strait of Georgia. Gill-netted samples are indicated by an asterisk.

formed a larger percentage (64) than any other group of III's in the series, it failed to form a dominant group as IV's in 1934-35. The age composition for 1916-17 (based on 5 samples) differs considerably from that of Thompson (1917) for the same season (based on 1 sample) but the difference may be attributed to school variation.

The age histograms for material taken by seine and jig from Departure bay (1932-33; 1934-35) and by seine from Pender harbour (1933-34) are essentially similar to those for Saltspring island. Those from Granite bay and Hammond bay (1933-34) differ somewhat in that the 1929 year class is relatively more abundant at age VI, predominating over adjacent classes. Comparison of the non-selected material from Departure bay (1932-33) and Pender harbour (1933-34) with that taken in gill nets, 2- to 2½-inch (ca. 5 to 6 cm.) stretched measure, shows that II's are not captured, III's are taken in relatively smaller numbers, and V's, VI's and VII's are taken in relatively larger numbers in the latter. The IV's in gill-netted samples were much more numerous at Pender harbour and slightly less numerous at Departure bay. Therefore, considering the selectivity of the nets, the gill-netted samples from point Grey indicate that in this locality the 1929 year class was particularly abundant, dominating to age V and forming a large percentage (20) at age VI; the 1930 year class was but poorly represented; and the 1931 year class was fairly abundant. It would appear, therefore, that in the strait of Georgia, the year classes vary in strength from year to year and that conditions causing this variation tend to be widespread each year. Thus, while there is some variation, the year classes 1929, 1931 and 1932 appear to be more abundant than that of 1930 in most localities.

For Barkley sound, on the west coast of Vancouver island, data are available for two early and six recent years (figure 7). The age composition for 1915-16 is based on one large sample and that for 1916-17 is from Thompson (1917). In early years, ages ranged from III to over XI, and III's, IV's, V's and VI's together comprised 71 (1915-16) and 91 (1916-17) per cent of the samples. The 1912 year class was strongly represented and dominated over all other age groups at age IV and, in contrast with the same year class on the east coast of Vancouver island, again the following year at age V. In the recent six-year period the bulk of the catch (97 to 100 per cent) has consisted of fish of age II to VI, and fish of age III have consistently predominated over all other age groups, forming from 46 to 71 per cent of the catch. In recent years, the age composition appears to have fluctuated less widely as compared with that of Saltspring island and that of Barkley sound itself in early years.

The age compositions of catches in most other localities on the west coast of Vancouver island have varied from year to year to a much greater extent than that of Barkley sound. The 1931 year class was much more abundant in 1933-34 (III's) at Sydney inlet, Nootka sound and Kyuquot sound; the 1929 year class predominated at Kyuquot sound in 1932-33 (IV's); the 1928 year class predominated at Sydney inlet in 1931-32 and 1932-33 (IV's and V's); and the 1927 year class was dominant at Quatsino sound in 1932-33 (VI's). The age compositions for Sydney inlet and Quatsino sound are worthy of special note as they differ so radically from all others on the west coast of the island. In the former, year classes 1929, 1928, and 1927 were all well-represented in 1931-32 (III's, IV's, and V's) and again in 1932-33 (IV's, V's, and VI's), but in the following season, year class 1931 was strongly dominant, forming 78 per cent of the catch (III's). In the latter, although the estimations are based on but one or two samples each year, there is also a strong tendency for these same year

classes to be present as relatively abundant groups from 1932-33 to 1934-35 (VI's, VII's, and VIII's in the latter season) but with year class 1927 rather than 1928 tending to predominate. The presence of these three classes caused the progression of the mode "A" in the length frequency curves (figure 4). There

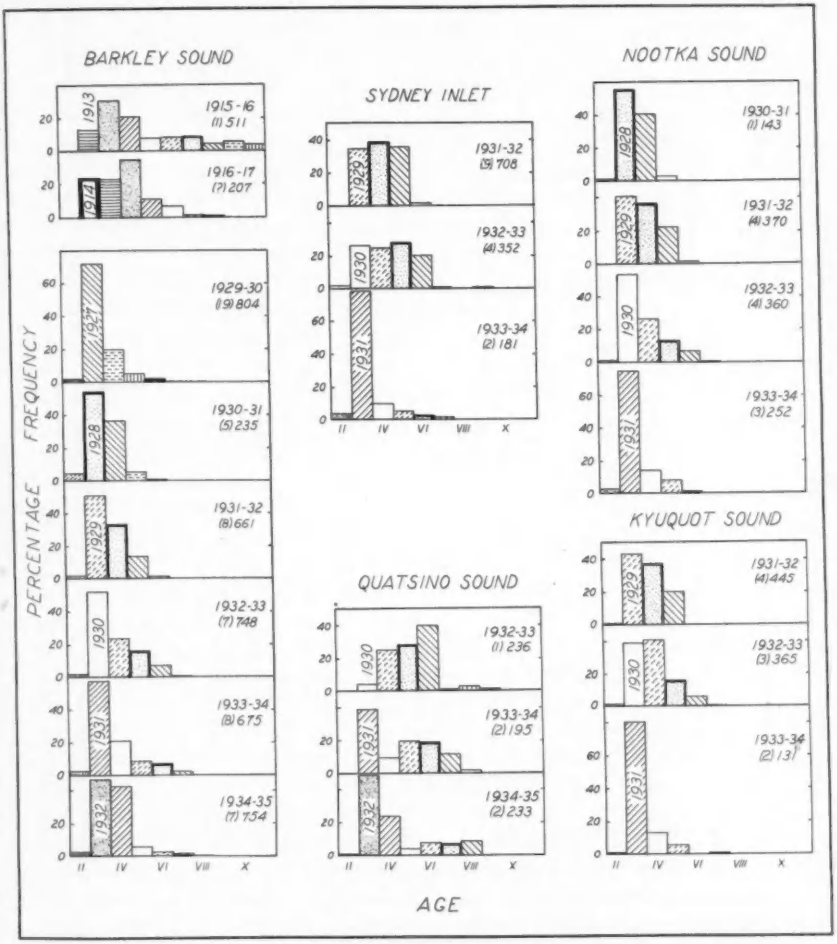

FIGURE 7.—Age composition of herring from Barkley sound and other localities on the west coast of Vancouver island.

appears to be a much greater prevalence of old fish (age V or more) in Quatsino sound than in all localities to the south.

As all estimates of age composition in localities north of Vancouver island are based on but one sample each season, they must be considered as only indicative of general conditions in each. The Bella Bella samples are not con-

sistent with each other in that a predominance of the 1929 and 1927 year classes (IV's and VI's) are present in 1932-33 but not in 1934-35, year class 1928 (VII's) predominating in the latter season. This same year class (1928) was strongly dominant at Bella Coola, situated at approximately the same latitude but several miles inland, in 1933-34 (V's). At Jap inlet to the north, data for four seasons

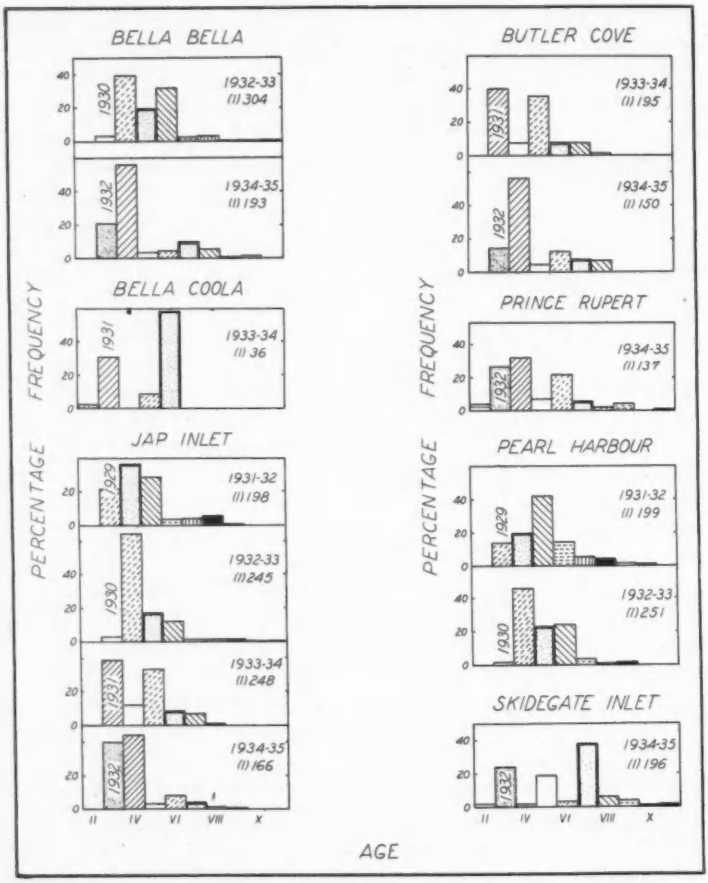

FIGURE 8.—Age composition of herring from localities to the north of Vancouver island.

enable the passage of the relatively rich 1929 year class to be traced through the catches. This class, entering the fishery at age III in 1931-32, dominates at age IV in 1932-33 and remains more abundant than adjacent year classes up to age VI in 1934-35. The large percentage of III's in 1933-34 and of III's and IV's the following year indicates that both the 1931 and 1932 year classes are well represented. In the age compositions for Butler cove and Prince Rupert harbour the same year classes predominate as at Jap inlet. Although the 1929

year class is also an abundant group at Pearl harbour, in contrast to the results for Jap inlet, year class 1927 is better represented than that of 1928 in 1931-32 and 1932-33 (V's and VI's). The age composition for Skidegate inlet in 1934-35 is unique in that there are three outstanding groups: year classes 1932 (III's), 1930 (V's) and 1928 (VII's). Classes 1927, 1929, and 1931, which were relatively abundant in most localities, formed but small percentages in this sample.

Whereas in several localities throughout the waters of the province the same year classes tend to be relatively strong (*e.g.* 1929) or relatively weak (*e.g.* 1930), in others their relative strengths may be quite different. This variation is to be expected as intermingling between many of the runs is limited. Although no significant differences in "racial" characters have been demonstrated between herring from Sydney inlet and those from Barkley sound to the south and Nootka sound to the north, the unique age composition encountered in this locality from 1931-32 to 1933-34 is evidence that it tends to form a local population. Similarly, the age composition of the Skidegate inlet herring and the Pearl harbour herring suggests the lack of extensive intermingling of these populations with others in Hecate strait.

Age at Maturity and for Commercial Capture

Two separate groups of immature herring are often present in the summer in inshore waters, the first consisting of fish of the year and the second of older individuals. A sample of the latter taken with a drag seine (Barkley sound, June 19, 1933) gave for fifty fish 12 II's, 36 III's, 1 IV and 1 V. One of the III's and the two older fish were the only individuals classified as mature, although in all the III's the gonads were sufficiently developed to lead one to expect that they would spawn the following spring. Of herring taken in the winter purse seine fishery about 80 per cent of the II's, which form only 1 to 2 per cent of the catch, 4 per cent of the III's and less than 1 per cent of the IV's were considered immature (Saltspring island, 1931-32 to 1934-35). This shows that while most are first mature at age III, some mature as II's (individuals with fully developed eggs were once taken on the spawning grounds) and some apparently not until age IV and V. Histological examination and observations on the progressive ripening of the gonads of point Grey summer herring indicate that the large seemingly "immature" fish of Thompson (1917) were spents which were recovering from an unusually late spawning. As herring in the commercial runs consist almost entirely of mature fish it seems probable that the addition of new recruits to these is governed by the onset of maturity.

In southern British Columbia herring enter the schools supporting the purse seine fishery for the most part at age III. This is shown in figures 5 to 7, where in almost every instance a year class forms a much larger percentage of the catch at age III than in the following year at age IV. Some, however, also enter at age II and others may also enter at age IV or V. In the gill net fishery size of mesh determines the minimum age, that employed in the strait of Georgia taking a few fish of a year class at age III but a much larger percentage at age IV.

In northern British Columbia, while in certain localities some II's are found in the pre-spawning runs (figure 8), in most places a year class appears for the first

time at age III and forms a still larger precentage of the catch at age IV in the following year. Thus at Jap inlet year classes 1929, 1930 and 1931 formed respectively 22, 3 and 39 per cent at age III, and 64, 12 and 44 per cent at age IV. North of Vancouver island, therefore, as in Alaska (Rounsefell and Dahlgren, 1932), herring enter the commercial fishery in part at age III but in force at age IV. This difference between the southern and northern runs may be due to growth being slower in the north (Tester 1937), slow growth being associated with a retarded inception of maturity (Hubbs 1926).

The Phenomenon of Dominance

The fluctuations in length and age which have been found to occur in the herring runs of British Columbia differ in several respects from those in other great herring fisheries.

Firstly, as shown in a preceding section, different year classes may form the most abundant group in localities separated by but a few miles (Sydney inlet and Nootka sound, 1931-32; Quatsino sound and Kyuquot sound, 1932-33; Skidegate inlet and Jap inlet, 1934-35; etc.). Rounsefell and Dahlgren (1935) have found a diversity in age composition in southeast Alaska similar to or even more marked than that reported here. In marked contrast to these findings, Hjort and Lea (Hjort 1926) have demonstrated that along the coast of Norway over a distance of five degrees of latitude, samples from various regions are very similar to each other in one season, the same year class being dominant in each. This difference between the herring of British Columbia and Alaska and those of Norway is doubtless related to the tendency for the former to form local populations.

Secondly, successive year classes appear to be more uniform in abundance than in most other regions. This is particularly the case in southern British Columbia where in one region (Barkley sound, 1929-30 to 1934-35) each incoming year class has in turn predominated in the catch at age III; in most regions variation has been sufficient to allow the more abundant groups to dominate for two years at ages III and IV and to form larger percentages than adjacent groups until age VI; and in only a few instances year classes have dominated at age V (Barkley sound, 1916-17; Sydney inlet, 1932-33) and age VI (Quatsino sound, 1932-33). In northern waters, successive year classes appear to be more unequal in relative abundance and to maintain a predominance over adjacent age groups to a greater age. Here, certain year classes have dominated the catches in certain regions at ages III, IV, V, and in one case, VII. These conditions are in contrast to those in Alaska where Rounsefell (1930) has shown year classes to be dominant at ages VIII and IX and to predominate over adjacent groups until age XII (Prince William sound) and Rounsefell and Dahlgren (1932 and 1935) found that one year class (1926) formed over 80 per cent of the catch at ages IV and V (Prince William sound and southeastern Alaska). This same year class at the same ages formed but 23 and 9 per cent (Saltspring island) and 20 and 5 per cent (Barkley sound) in southern British Columbia. In still more marked contrast are conditions in Norway where it has been shown that exceedingly rich year classes (*e.g.* that of 1904) may appear

at long, irregular intervals of time and dominate in the catches until at least age XV. Comparison of the results of Hodgson (1929 and 1932) for the East Anglian drift net fishery of the North sea with those for gill-netted herring from the strait of Georgia shows more marked fluctuations in the former, although reliable comparison cannot be made without considering the size of mesh employed in each. In this North sea fishery there has been a tendency for dominant groups to appear every three years. A tendency for successive year classes to be alternately richly and poorly represented may be noted for certain localities in British Columbia but, on the whole, this sequence has not been maintained consistently.

The difference between the British Columbia herring and those of Alaska, Norway and the North sea in regard to the degree of dominance and the persistence of dominant year classes in the catch is probably related to differences in the age at maturity and the rate of mortality. Hodgson (1932) has pointed out that fish which mature at an early age, such as those in the Baltic sea, have a higher mortality rate than those which mature at a later age, such as those of Norway. In consequence, the life span in the catch during which a year class contributes materially to the supply, or, as Hodgson (1929) has called it, the "effective" life of a herring, varies accordingly. In the Norwegian herring it is from 12 to 15 years, in the North sea drift-netted herring 8 or 9 years, in the Alaska herring 9 or 10 years, in northern British Columbia herring about 6 years (III to VIII) and in the southern British Columbia herring, particularly since 1929-30, about 4 years (III to VI). Because of the high rate of mortality, a rich year class does not dominate in the catches for as many years in the British Columbia fishery as in other regions. This, however, does not explain wholly why annual variations in the abundance of incoming year classes are less than in other regions. The latter is possibly related to more uniform physical, chemical or food conditions at the time of spawning and early development, or to the fact that a year brood in each locality is dependent on many small rather than one or two extensive spawnings, thereby reducing the element of chance.

Dominance a Cause of Abundance

Because of the more uniform strength of the year classes in British Columbia, fluctuations in abundance caused by year class variation should be less extensive and more difficult to demonstrate than in other regions. Before the latter can be accomplished a system of grading the year classes according to their relative abundance is necessary. Farran (1930) has shown how this can be accomplished by calculations which are based on the average rate of decrease in the relative abundance of a year class from one age group to the next. A similar method, based on the same principles, has been used by the author, but in this the labour of calculation has been reduced by comparing the actual with the expected percentage at age III only, and by using the average strength of a year class rather than the age composition in the first year of observation as a standard for comparison. This simpler method is sufficiently accurate for the British Columbia herring, where the incoming year class forms such a large percentage of the catch.

The unweighted average age composition of the catch at Saltspring island from 1929-30 to 1934-35 was as follows:

II	III	IV	V	VI	VII	VIII
1.3	50.4	32.3	12.0	3.3	0.6	0.1

From these figures the average percentage decrease of a year class from one year to the next was calculated:

III to IV	35.9
IV to V	62.8
V to VI	72.5
VI to VII	81.8
VII to VIII	83.3

The more refined method of Lea (1930) to find percentage mortalities was not used because of the short period under consideration. The above figures were applied to the percentages of III's, IV's, etc., of one year to obtain corresponding values for these groups as IV's, V's, etc., in the following year. The sum of these values (plus an allowance of 1.3 per cent for II's) when subtracted from 100 per cent, gave the percentage of III's which would be expected in the second year if the incoming year class were of *average* strength. By comparing the calculated values with those actually obtained, a measure of abundance of III's which was comparable from year to year was obtained. Thus, considering unity as average strength, the relative abundance of the members of the incoming year classes from 1930-31 to 1934-35 were as follows:

1928	1.03
1929	1.01
1930	0.74
1931	1.20
1932	0.98

From these results it would seem that the 1928, 1929, and 1932 year classes were of average strength, whereas that of 1930 was much below and that of 1931 considerably above average strength. As pointed out by Farran (1930) the reliability of such calculations depends on the percentage mortality remaining fairly constant from year to year. In other words, the calculated values for IV's, V's, etc., should be in approximately the same ratio as the actual percentages which are encountered. Percentage mortality, however, consists of two components, natural mortality and fishing mortality, and the latter at least does not necessarily remain constant from year to year. When there is a progressive change in mortality such as would be caused by an increasingly intensive fishery, approximate values for the relative strengths of the year classes may be obtained by confining calculations to short periods, *e.g.*, five or six years. Their reliability is also dependent on the assumption that the percentages of fish entering the fishery for the first time at ages greater than III remain constant. Errors involved in these assumptions may detract from the accuracy of the above values, but allowance cannot be made for them until additional information is available.

From a consideration of age composition it would be expected that the yield for a similar intensity of fishing would be less in 1933-34 than in 1934-35, for in the former season the bulk of the catch consisted of a rich (1931) and a poor (1930) year class, whereas in the latter it consisted of an average (1932) and a rich (1931) year class. From knowledge of the daily catch of each seine boat, first obtained in 1933-34, the average daily catch per seine was calculated at 67.2 tons (61.0 metric tons) in the former and 75.8 tons (68.8 metric tons) in the latter season, thus fulfilling the expectation. In both seasons the same type of gear (double seine) was used and approximately the same number of boats were fishing.

A great abundance of herring reported in 1918-19 (Tester 1935) may be attributed to the influx of a rich year class (1916) to the runs. Calculations based on percentage mortalities from 1915-16 to 1919-20 (p. 164), showed the relative strength of this year class, entering the fishery as III's in 1918-19, to be 1.6, which is considerably greater than that of other year classes in this early period.

Thus the limited data which are available indicate that annual fluctuations in the abundance of herring in the Saltspring island fishery are related to variations in the strength of successive year classes. In certain other localities, particularly those in northern British Columbia, such fluctuations may be expected to a slightly greater extent than at Saltspring island but to a lesser extent than in Alaska and Norway.

Trends in Length and Age Composition

Although length data are rather unsatisfactory, there is some evidence that on the average herring taken in recent years have been smaller than those taken in the early years of the two major purse seine fisheries (Saltspring island and Barkley sound). On the southeast coast of Vancouver island the average length from 1915-16 to 1925-26 was 195 mm. and from 1929-30 to 1934-35 191 mm. In Barkley sound during 1915-16 and 1916-17 the average was roughly 206 mm., the estimate being based on Fraser's measurements in the former and Thompson's (1917) in the latter season, whereas from 1929-30 to 1934-35 it was 191 mm. The smaller averages encountered in recent years have been accompanied by a decreased dispersion of lengths about the mean. The downward trend is illustrated by the straight line (figure 9A) which is fitted by least squares to the standard deviations given in table II for samples from the southeast coast of Vancouver island.

There is evidence that similar trends in age composition have taken place in the two major purse seine fisheries. On the southeast coast of Vancouver island there has been a slight decrease in both the spread in ages and in the relative abundance of older fish in the catches since 1915-16 (figure 5). The latter is more clearly shown by the percentages of fish older than age IV contained in table II and by the straight line fitted to these data in figure 9B. In Barkley sound more extensive changes in the same direction appear to have taken place (figure 7). Whereas fish older than IV formed 56.9 per cent in 1915-16 and 54.1 per cent in 1916-17, they have averaged but 12.9 per cent over the recent six-year period.

With the decrease in the relative abundance of older fish there has been an apparent decrease in the frequency of occurrence of dominant year classes. In the early years of the east coast fishery year classes were frequently dominant at ages III and IV, whereas in the recent six-year period only one has maintained its dominance until age IV (figure 5). Similarly in the early years of the Barkley sound fishery, the 1912 year class was dominant until age V, whereas in recent years each incoming year class has formed the bulk of the catch at age III.

TABLE II.—Standard deviation of length distribution (A) and the percentage of fish older than IV (B) for the material from the southeast coast of Vancouver island in each season

Season	A	B
1915-16	16.0	41.0
1916-17	14.7	33.8
1917-18	16.8	24.2
1918-19	15.3	21.6
1919-20	13.5	22.3
1920-21	....	....
1921-22	14.6	24.4
1922-23	17.8	19.0
1923-24	....	....
1924-25	14.1	20.5
1925-26	12.9	21.6
1926-27	....	....
1927-28	....	....
1928-29	....	....
1929-30	12.8	23.4
1930-31	13.8	12.1
1931-32	12.7	16.1
1932-33	13.0	14.0
1933-34	12.8	15.4
1934-35	12.0	15.4

Associated with all of these trends in length and age composition is an increase in the mortality rates as calculated from the latter. This is shown for the Saltspring island fishery by the following rates of decrease from one age to the next, calculated as in the method of the previous section:

Ages	1915-16 to 1919-20	1929-30 to 1934-35
III to IV	4.7	35.9
IV to V	49.6	62.8
V to VI	56.6	72.5
VI to VII	67.1	81.8
VII to VIII	72.0	83.8

The difference between the two series is fairly constant with the exception of the first comparison (III to IV) where a particularly low value is present in the early period.

The changes discussed above are similar to those which might be expected as a result of intensive exploitation. A decline in size and age due to fishing activity has been found in the plaice fishery of the North sea (Heincke 1913), in the halibut fishery of British Columbia (Thompson, Dunlop and Bell 1931; Thompson and Bell 1934), in the herring fishery of southeastern Alaska (Rounsefell 1931), etc. As the annual catch in British Columbia has increased greatly since 1915 and as this increase has resulted almost wholly from the more intensive

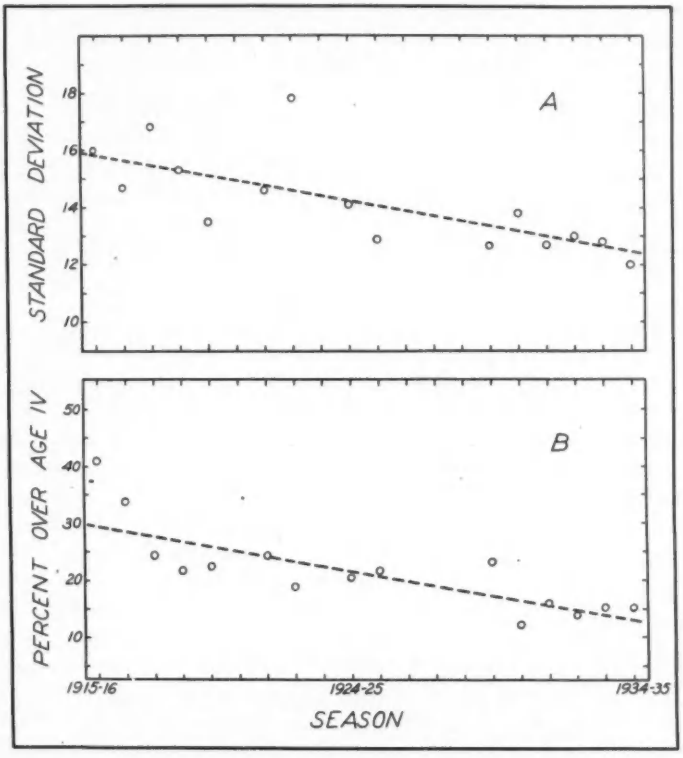

FIGURE 9.—(A) The trend in standard deviations and (B) the trend in the percentages of fish over age IV in the Saltspring island fishery from 1915-16 to 1934-35.

exploitation of the southeast and west coasts of Vancouver island (Tester 1935), the same explanation seems applicable. The increased fishing mortality would cause not only the decrease in length and age spread and the reduction in the numbers of larger and older fish, but also the decrease in the period of dominance of the richer year classes and the apparent decrease in their frequency of occurrence. Detailed catch records are not available to determine whether the decline in numerical abundance has been accompanied by a decrease in the weight of fish taken per unit of effort over the period. As the runs to Saltspring

island and Barkley sound tend to form local populations, such trends in length and age might be expected to be more pronounced and to appear in a shorter interval of time than in a migratory species subjected to the same intensity of fishing.

It may be noted that other populations in southern British Columbia which have not been fished intensively (*e.g.*, Quatsino sound, Sydney inlet previous to 1931-32) have a relatively greater supply of older fish. As fishing intensity has been greater in southern than in northern waters, this factor may explain in part the greater spread in ages and apparently greater year class variation in the latter.

The Possibility of Forecasting Length and Age Composition

Using the principles set forth by Lea (1930), Hodgson (1932) has shown that it is possible to forecast the length and age composition of North sea herring a year in advance with a fair degree of accuracy. Similar forecasts might be attempted for the British Columbia herring but their accuracy would be considerably less. Assuming that the sampling system is adequate to give reliable estimates of length and age distribution there remain at least two factors which would detract from the accuracy of such prognostications. Firstly, the mortality imposed on the stock by fishing activity fluctuates considerably from year to year chiefly because of varying market conditions. Changes in age composition which were probably caused by an increasing intensity of fishing since 1915 have already been shown. This renders difficult any attempt to obtain reliable figures for the percentage mortality from one age group to the next. Secondly, in southern British Columbia in particular, the incoming age group (III's) forms a very large proportion of the catch (often over half) and, at present, there is no advance information available concerning its relative abundance. Future investigation may reduce this uncertainty to some extent by revealing a relationship between the relative abundance of the small numbers of II's in the catch and that of the III's in the following year, or by supplying information on the relative abundance of immature fish before they join the commercial schools. Until such knowledge is available, however, the forecasting of size and age and, the ultimate goal, abundance, is subject to such severe limitations as to render it of doubtful practical value.

SUMMARY AND CONCLUSIONS

A general survey of the length and age composition of the herring of British Columbia, based on random samples from the purse seine and gill net fisheries and from the spawning grounds, is made with the primary object of determining the extent of annual variation. Ages are determined from the scales, those in northern waters being more clearly marked. In southern waters 7 or 8 per cent of the estimations are doubtful, but this does not detract from the reliability of general conclusions.

It is shown that significant differences in length and age composition are present between different catches and presumably different schools of fish in the

same locality and season. Several samples from each are necessary to obtain a reliable estimate of these two characters.

Smoothed length frequency curves vary considerably in shape and position in the various runs in the same year and in certain runs from year to year. The spread in lengths is greater in northern than in southern populations. In some, bimodal curves are encountered and the positions of the modes progress from year to year.

In general ages range from II to XI and only rarely are older fish encountered. The bulk of the purse-seined catch in southern waters is composed of ages III to VI and in northern waters of ages III to VIII. In the two major fisheries of southern British Columbia (Saltspring island and Barkley sound) III's form from 38 to 71 per cent and III's and IV's together from 76 to 91 per cent of the catch from 1929-30 to 1934-35.

In southern waters members of an incoming year class join the runs of mature fish in force at age III, whereas in northern waters they join in part at age III and in force at age IV. This difference may be related to the slower rate of growth in the north. The addition of new recruits seems to be related to the onset of maturity.

Due to the tendency for the Pacific herring to form local populations, a considerable diversity in age composition is present among the various runs. In localities separated by but a few miles different year classes may form predominating groups.

Dominance of a type is encountered. In southern waters an abundant year class may form a dominant group in the purse seine catches at ages III and IV but is then overshadowed by a new group entering the fishery at age III. It may continue to predominate over adjacent age groups at ages V and VI. Instances of year classes dominating at ages V and VI are present but rare. In northern British Columbia year classes may persist as dominant groups to a somewhat greater age. These conditions, in marked contrast to those in Alaska and most European "races", are the result of the high rate of mortality. The relatively small extent of variation in the strengths of successive year classes may be caused by more uniform water conditions during and subsequent to spawning or by the multiplicity of spawnings.

The relative strengths of successive year classes in the Saltspring island fishery are calculated by comparing the observed with the expected percentage of fish at age III. An increased catch per unit of fishing effort in 1934-35 and an abundance of herring reported in 1918-19 are probably caused by the presence of relatively rich year classes.

In the Saltspring island and Barkley sound fisheries, certain trends in length and age composition have taken place over a twenty-year period. These trends, namely, a decrease in average length and age, a decrease in length and age dispersion, a decrease in the frequency of occurrence and persistence of dominant year classes, and an increase in the percentage mortality from one age group to the next, are probably caused by an increased intensity of fishing activity in recent years.

Because of the variations in fishing intensity and because of the large proportion of the catch formed by the incoming year class, forecasts of length and age composition and of abundance cannot be made with a reasonable degree of accuracy until additional information is at hand.

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The Number of Vertebrae in Trout (*Salmo*)

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(*Received for publication February 17, 1937*)

ABSTRACT

The European species of *Salmo* have fewer vertebrae than those from western North America, the mean values of two of each group as reared at the Cowichan hatchery being found to be: *salar* 59.0, *trutta* 58.3, *gairdnerii* 63.5, *clarkii* 62.5. Hatchery-reared *gairdnerii* were usually found to be different from those of the natural environment as well as varying with different experimental conditions, and even differed from their own parents, this seeming on the whole to be related to the temperature during development. A correlation was found between the length of the fish and the number of vertebrae. Caution is suggested in the use of the character for identifying populations of *Salmo*.

The number of verterbrae is a character commonly used by systematic zoologists for the identification of species and varieties of fish, and it has also been extensively employed by economic fishery biologists for the purpose of identifying populations. Recently it has become one of the more important tools for investigating life-history problems.

Two leading schools of thought have developed in connection with the use of the number of vertebrae in fisheries investigation: one group holds that the number of vertebrae is determined within fairly broad limits by hereditary factors, but that the number finally laid down may be determined by the combined action of a number of external environmental factors; the other group holds that the character is determined by heredity alone. It is obvious that the correct interpretation of data concerning this character depends to a great extent on the question of its modifiability. The identification of a certain population of fish is a relatively simple matter if it is characterized by a fixed vertebral number; on the other hand, it becomes an exceedingly difficult matter if the character constantly fluctuates from one generation to the next depending on the influence of the various environmental factors.

In the course of biometrical studies of the trout of British Columbia an opportunity has been afforded to investigate the number of vertebrae in several populations, and in examining this material there appeared to be certain inconsistencies in the various samples which have pointed to a confirmation of the belief that environmental conditions do affect the number of vertebrae in trout. It is the purpose of the present paper to set forth: (1) the vertebral characterizations of Kamloops trout, *Salmo gairdnerii kamloops*, from naturally occurring populations; (2) the vertebral characterizations of the four species of trout

reared in the hatcheries of British Columbia; and (3) the main results of certain experiments in which the number of vertebrae was modified by altering the enrivonmental conditions.

MATERIAL AND METHODS

Twenty samples were obtained from the three sources mentioned above and six varieties of *Salmo* were represented. The information concerning each sample is contained in table I.

Table I. Number of vertebrae in twenty samples of Salmo

Sample No. Source	Frequency of number of Vertebrae												Statistical Constants*				
	56	57	58	59	60	61	62	63	64	65	66	67	(N)	(M)	(σ)	(σ_M^2)	(C.V.)
Naturally occurring populations																	
S. gairdneri Kamloops																	
1. Redfish creek, Aug. 1930.							4	22	21	3			50	63.46	0.73	0.01	1.2
2. Lardeau river, May, 1930, parents of sample 15.									12				12	64.00	0.00	0.00	0.0
3. Paul creek, Sept. 1931.							1	7	11	5	1		25	63.92	0.89	0.0324	1.4
4. " " Sept. 1932.								13	12				25	63.48	0.05	0.0001	0.79
5. S. gairdneri whitehousei Six Mile lake, June and Oct. 1930							7	17	17	6	2		49	63.57	1.01	0.0196	1.6
Samples from hatcheries																	
Cowichan hatchery																	
6. S. gairdneri, Cowichan R. stock, 1931.								14	10	1			25	63.48	0.61	0.0144	0.96
7. " clarkii, Cowichan L. stock, 1931.						1	12	10	2				25	62.52	0.70	0.0196	1.1
8. " trutta, imported from Wisconsin, 1931.		3	12	9	1								25	58.32	0.73	0.0225	1.2
9. " saler, imported from Thurso R., Scotland, 1933.			3	15	4	1							25	59.04	0.72	0.0196	1.2
Nelson hatchery																	
10. S. g. kamloops (Pennask lake) Imported July, 1930; killed Oct. 1930.							4	10	8	3			25	63.40	0.61	0.0144	0.96
11. " " whitehousei (Six Mile lake) 1930.							6	25	15	4			50	63.34	0.79	0.0121	1.2
12. " " " (Cottonwood lake) 1930.								4	11	6	4		25	64.40	0.94	0.0361	1.5
Lloyd's creek hatchery																	
13. S. g. kamloops, Paul lake, Sept. 1931.							1	5	6	5			17	63.88	0.90	0.0484	1.4
14. " " " Paul lake, Sept. 1932.								2	11	9	2	1	25	64.56	0.90	0.0324	1.4
Samples from experiments																	
15. S. g. kamloops (broods 1-6)[1]								17	66	58	9		150	64.39	0.76	0.0036	1.2
16. " " " (brood 2)[2]								11	36	3			50	63.84	0.50	0.0049	0.79
17. " " " (brood 2s)[3]								5	39	6			50	64.02	0.47	0.0049	0.73
18. " " whitehousei (o)[4]							3	9	12	1			25	63.44	0.75	0.0225	1.2
19. " " " (A)[5]	1	1	2	6	13	14	25	47	57	29	3		200	62.90	1.76	0.0154	2.8
20. " " " (A_2)[6]			2	1	3	4	11	13	14	1	1		50	62.54	1.65	0.0484	2.6

* N,- number; M,- mean; σ,- standard deviation; σ_M^2,- square of standard deviation of mean; C.V.,- coefficient of variation.

1. Eggs spawned at end of run at Gerrard on Lardeau river, May 23, transferred to the Nelson hatchery; each brood kept separate, 25 fish from each brood; sample killed Oct. 7, 1930.
2. Brood 2 from above - killed October 7, 1930.
3. A part of brood 2 reared under higher temperature conditions after the eyed-egg stage in scale-count experiments. (for details see Mottley 1934A).
4. From eggs spawned at Six Mile lake on June 13, 1930; reared at Nelson hatchery under higher temperature conditions, as in (17), until August 9, 1930; killed October 7, 1930.
5. Same source as (18) spawned on June 7, 1930, held for first three weeks under temperature lower than normal, obtained by packing containers in ice and reducing flow of water; then returned to normal conditions by allowing the ice to melt and increasing the flow of water, killed on October 7, 1930.
6. Fingerlings from same population as (19), killed on February 15, 1931.

For the purpose of this study the vertebral counts have been made chiefly on fry or fingerlings, fish 20 to 75 mm. in length. Trout of this size are particularly useful for this characterization because they can be easily handled in large numbers and lend themselves more readily to the staining technique and dissection. All of the material in this investigation except sample 2, which consisted of adult fish, was stained with alizarine by Tåning's method (1927), and was stored in a mixture of equal parts of alcohol (95 per cent), glycerine and water. In order to make the count, the muscles of the right side of the body were removed and the head was sectioned longitudinally just to the right of the mid-line, so that the entire vertebral column was exposed. A stereo-binocular microscope was used to facilitate the counting.

The first centrum bearing a neural process was taken as the first vertebra in the count. The centra and their neural processes were used as the indices of the vertebrae as far as the fiftieth, thence the centra alone were counted using the criterion of a distinct centrum as the index. The last centrum stained red was taken as the last vertebra in the series; since the urostyle did not stain it was not counted.

Some investigators have adopted the practice of counting the neural and haemal processes, using them both as the index of a vertebral element in order to avoid the difficulties encountered by the presence of fused centra. Schmidt (1921) has expressed the numerical signification of this so-called abnormality. In recording the enumeration on cod, Schmidt (1930) remarked that a fusion of the vertebrae is not rare between the third and fourth vertebrae from the end of the tail. Ford (1933) has shown the percentage of occurrences of abnormalities in different sections of the vertebral column of herring and has indicated that the majority of the variations encountered are localized in the "tail" region. In the trout samples there was a noticeable irregularity, usually occurring anterior to the up-turning of the vertebral column at the fourth, fifth or sixth vertebra from the urostyle. A considerable error can thus arise depending on the procedure adopted in enumerating the number of vertebrae in the caudal region. An example of this was afforded by sample 3. In 9 out of 25 cases, or 36 per cent of the sample, the number of vertebrae could be stated in two ways; first when using the neural and haemal processes as the criterion of a vertebra, and, second, the number of centra. The data are as follows:

Number of vertebrae...	62	63	64	65	66
First method.....	0	2	15	7	1
Second method.....	1	7	11	5	1

Statistical constants....	(M)	(σ)	(σ_M)	(C.V.)
First method.....	64.28	.67	.13	1.04
Second method.....	63.92	.89	.18	1.40

(D) = .36 (σ_d) = .22

The difference between the samples is 1.6 times its own standard error; the normal deviate would be expected to fall outside this range in 11 per cent of

such cases, hence the difference may be considered as being within the limits of probable significance. The values for the coefficient of of variation (C.V.) show that the second method gives a greater degree of variation. In making a comparison with the data of other investigators, however, it should be noted that in the caudal region, if the centra were stained as discrete blocks they were counted separately, if the separation was not complete they were counted as one.

ANALYSIS OF THE DATA

The data are presented in table I in the form of frequency distributions together with the statistical constants derived therefrom.

They comprise the vertebral characterizations of four distinct taxonomic groups: two Atlantic species, *S. trutta* and *S. salar*, and two Pacific species, the rainbow group consisting of *S. gairdnerii*, *S. gairdnerii kamloops* and *S. gairdnerii whitehousei*, and the cutthroat group represented by *S. clarkii clarkii*. Four of these species were reared at Cowichan hatchery on Vancouver island namely, *trutta*, *salar*, *clarkii* and *gairdnerii*. The (M) values in samples 6, 7, 8 and 9 show that the four groups are distinctly different. The Atlantic forms are characterized by fewer vertebrae and there is practically no overlapping between the ranges of the Atlantic and Pacific species. Within these groups *trutta* has fewer vertebrae than *salar*, and *clarkii* has fewer than *gairdnerii*. This parallel between the salmon-like forms (*salar* and *gairdnerii*) and the trout-like forms (*trutta* and *clarkii*) is interesting because it is also evident in a number of other characters, viz., the fin rays and gill rakers.

Within the rainbow group the difference between samples 6, 1 and 5 is not significant, although there is an increase in the coefficient of variability in the order named. The variability may possibly be associated with a climatic factor; it is well known that the daily and seasonal temperatures are more variable at higher altitudes. Sample 6 came from an altitude of 500 feet (150 m.), sample 1 from 2,200 feet (670 m.), and sample 5 from 3,300 feet (1,000 m.). Samples 3, 13 and 14 from the Paul lake area, 2,600 feet (800 m.), have a C.V. value of 1.4 which is intermediate between samples 1 and 5.

A survey of the data shows that there is a significant difference between hatchery reared fish and those from natural conditions. Samples 1 and 15 from the Kootenay lake area illustrate this difference. The difference between the means is 0.93 and the standard error of the difference is 0.12; the difference, being over 7 times its own standard error, may be considered as significant. The fish in sample 15 are also significantly different from their own parents, sample 2. The samples from the Paul lake area taken in 1932 also illustrate the difference between hatchery reared fish and fish from the natural environment; for example, the difference between the means of samples 4 and 14 is 1.08 and the standard error of the difference is 0.18. The difference is 6 times its own standard error, and is, therefore, significant.

A possible interpretation of these data is based on the fact that the trout hatcheries in British Columbia are situated on cold snow- or spring-fed streams and these are not normally chosen by rainbow trout at spawning time. The writer has described (Mottley 1934B) how the spawning fish tend to choose

streams with temperature conditions nearer an optimum (6° to 10°C.). In the spring this optimum range is reached earlier in the season by streams that serve as the outlet of a lake than by streams fed by springs and melting snow. Consequently fish that are reared in the hatcheries are subjected to an entirely different set of conditions from those of the natural environment.

Samples 3 and 4 illustrate the influence which the character of the stream may have on the number of vertebrae. Paul creek drains Pinantan lake and flows into Paul lake; midway between the two lakes Paul creek is joined by Lloyd's creek which is fed by springs and snow-water and at the time of the spawning run is usually at least three or four degrees colder than Paul creek. In extremely dry years Paul creek above the junction with Lloyd's creek does not flow and the stream bed remains dry throughout the year, but Lloyd's creek never goes dry. In 1931 there was no overflow from Pinantan lake, but in 1932 a considerable amount of water came down the channel. Paul creek in 1931 consisted of cold spring water coming from Lloyd's creek alone, whereas in 1932 there was a mixture of the cold, spring water from Lloyd's creek and the warmer "overflow" water from Pinantan lake. In 1932 the fish were all forced to spawn below the junction of the creeks because a barrier was constructed to prevent their ascent. The difference between the means of these two samples is 0.44 and the standard error of the difference is 0.18; the difference is 2.4 times its own standard error and hence is significant. There is also a significant difference between the C.V. values; the 1931 sample has a significantly higher coefficient of variation.

The difference between the vertebral counts of the fish reared in the Lloyd's creek hatchery and those from natural conditions in 1931 is not significant, as shown by samples 3 and 13. This is to be expected since they were all reared in the same kind of water, i.e. Lloyd's creek. In 1932, however, the means (samples 4 and 14) differed by 1.08 which has already been shown to be significant. Sample 4 was reared at the hatchery in Lloyd's creek water, whereas sample 14 was reared under natural conditions in the mixture of warm Paul creek water and the colder Lloyd's creek.

Samples 13 and 14 demonstrate the fact that fish of different year groups reared in the hatchery may have significantly different vertebral counts. The means of these samples differ by 0.68 with a standard error of 0.28. The difference is 2.4 times its own standard error and is therefore significant. This difference is probably attributable to the fact that in 1932 the spring was much colder than in 1931; the mean monthly temperature for May, 1931, at Kamloops was 3.6°C. above the normal average; in 1932 it was normal, being 14.4°C.

The six broods of fingerlings which make up sample 15 provide an interesting example of the variability of different broods spawned at the same time and reared under the same environmental conditions. The data are the more interesting because all the parents had 64 vertebrae and the progeny of each parent were reared in separate containers. The following table presents the statistical data for these fish; the ratio of the difference between the mean value of each brood and the mean of the six broods taken together (25 samples of each) to the standard error of the difference is represented by $\frac{D}{\sigma_d}$:

	(N)	(M)	(σ)	σ_M)	(C.V.)	$\frac{D}{\sigma_d}$
Brood 1	25	63.72	0.53	0.11	0.83	5.1
2	50	63.84	0.50	0.071	0.79	5.9
3	50	64.32	0.51	0.072	0.79	0.74
4	25	64.60	0.49	0.098	0.76	1.8
5	25	65.36	0.48	0.096	0.73	8.8
6	50	64.74	0.44	0.062	0.68	4.0
Broods 1-6	150	64.39	0.76	0.062	1.2	...

The mean of brood 3 is clearly not significantly different from the mean of the six broods; in the case of brood 4 such a deviation would be expected in only 7 per cent of such samples; the differences of the rest of the broods from the group mean are undoubtedly significant. Although these fish were exposed to similar environmental conditions they did not all hatch at the same time. Hatching was observed to extend over two or three days and broods 1 and 2 seemed to be earlier than the rest. However, it was impossible to determine a reliable hatching end-point. Factors associated with the determination of the time of hatching may thus affect the number of vertebrae and these factors may possibly be inherited. The amount of yolk has been shown to influence the rate of development, and may be the factor involved in determining the time of hatching.

Sample 19 demonstrates conclusively that the number of vertebrae in trout can be modified under experimental conditions. This sample is important because some of the values recorded are lower than any that have been found for the trout of British Columbia. The mean for sample 19 differs from the mean of sample 11—which may be regarded as a control because the fish were reared under normal hatchery conditions—by 0.44, and the standard error of the difference is 0.166. The difference is 2.6 times its own standard error and hence is significant. It must be inferred, therefore, that the treatment to which this sample was subjected produced the difference. The treatment involved holding the developing eggs in jars used for hatching whitefish (*Coregonus*) under temperature conditions colder than the normal for the first three weeks, then returning them to normal hatchery temperatures. Colder conditions were obtained by packing the jars in ice and reducing the flow of water into them. Since about 2,000 eggs were placed in this jar it is conceivable that there may have been a scarcity of oxygen owing to the reduced flow of water. In a parallel experiment where the flow was still further reduced the eggs all perished and this was ascribed to smothering. An alternative explanation may be advanced by assuming that temperature determines the number of vertebrae at a critical stage in development. Holding the eggs under colder conditions at first may have caused a protraction of development, then when the temperature was suddenly raised the formation of the vertebrae in the tail region was hastened and finally cut short. The net result would be the formation of fewer vertebrae. Since the normal hatchery temperature rises as the season goes on, the specimens with the number of vertebrae below the normal range, i.e., below 62, would

possibly be from those eggs in which development had been retarded so that the number was determined by a temperature higher than normal. Whatever the cause of the change, this experiment clearly shows that the number of vertebrae can be modified.

Sample 18 was reared at a temperature approximately 5°C. above the normal hatchery temperature, but the difference between this sample and sample 11 is not significant. It would seem, therefore, that the relationship, the higher the temperature the lower the vertebral count, does not necessarily hold experimentally, although Jordan has postulated a general law in nature to this effect. Schmidt (1920) has suggested that the high values for the number of vertebrae are produced by high and low temperatures whereas the low values are produced at intermediate temperatures, and expresses the relation between temperature and the number of vertebrae by a V-shaped curve. Samples 16 and 17 were reared at temperatures differing by about 5°C. The difference between the means of the two samples is not significant, but it is possible that the values fall on different segments of the curve. If this is so, then, had they been reared at temperatures only 2°C. or 3°C. apart, the difference might have been significant.

The general law which Jordan has described is probably true as far as it goes, because in nature the vertebral counts seem to be determined in general by those temperatures related to the descending limb of the V, but it is conceivable that conditions might also exist where the number of vertebrae is determined by higher temperatures related to the ascending segment of the curve. The latter relationship would be expressed in general by the law: the higher the temperature the higher the vertebral count.

Sample 20 was killed on February 15, 1931, whereas sample 19 was killed on October 7, 1930. A comparison of the means of the two samples shows that there is no significant difference between them. It may be inferred from these data that there was no definite selection in natural hatchery mortality, during the 130 days which elapsed. This might not have been the case, however, had this population been exposed to predators, since it is generally believed that as a trout grows larger it can more easily avoid its enemies.

The following table expresses the relationship between the standard length and the number of vertebrae for the 200 individuals in sample 19.

		No. of vertebrae											
		56	57	58	59	60	61	62	63	64	65	66	
Length in mm.	22	..	..	..	1	1	3	2	4	1	1	..	13
	25	1	1	1	3	6	5	6	12	15	6	1	57
	28	..	..	1	2	5	3	6	14	18	9	1	59
	31	..	..	..	..	2	2	6	10	16	8	..	44
	34	..	..	..	..	1	1	5	7	6	4	1	25
	37	..	..	..	..	..	..	..	..	1	1	..	2
		1	1	2	6	15	14	25	47	57	29	3	200

The correlation coefficient for this relationship is .237 with a standard error of .0639, which is significant. Thus, if there had been a differential mortality in which a greater proportion of the smaller fish was killed off, an entirely different distribution for the number of vertebrae with a different mean value would have resulted.

CONCLUSIONS

The number of vertebrae in the four species of *Salmo* now found in British Columbia was found to be significantly different. The two Atlantic species *salar* and *trutta* have fewer vertebrae than the two Pacific species, *gairdnerii* and *clarkii*. It has also been shown that the number of vertebrae in *Salmo* is extremely unstable. A significant difference was found between hatchery-reared *gairdnerii* and those from the natural environment, and fish of different year groups reared in the hatchery had significantly different vertebral counts. Furthermore, fish reared in the hatchery had vertebral counts significantly different from their own parents, and broods reared in parallel under similar hatchery conditions were also different. The number of vertebrae was modified by experimental methods but there was no evidence of selection under hatchery conditions. However, in a brood reared under experimental conditions there was a significant correlation between the length of the fish and the number of vertebrae, which might favour selection in a natural environment if a greater proportion of the small fish were caught by enemies.

The fact that the number of vertebrae in trout is capable of modification by changing the environmental conditions during development suggests caution in the use of it as a character for identifying populations of trout.

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Dissolved Nitrogenous Materials in the Effluent of Pilchard Reduction Plants

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(*Received for publication January 23, 1937*)

ABSTRACT

Fractional protein analyses of material from plants on the west coast of Vancouver island give the following average percentages of nitrogen: protein, 7.6; proteose, 35.9; peptone, 26.9; and sub-peptone 28.5. "Dissolved protein" precipitated by "methyl hydrate" consists of both protein and proteoses.

In the methods at present employed in the pilchard reduction plants on the west coast of Vancouver island, large losses occur in the effluent discharged from the oil separation tanks. Beall (1933) made a study of these losses and recorded the amount of oil, suspended meal, and "dissolved protein" lost.

The present paper is an extension of this work in so far as the dissolved material is concerned. Since the nitrogenous fraction of the dissolved matter is the most important economically, fractional protein analyses were carried out on various effluent samples. At the same time, the total solids and ash content were determined. Analyses were also made to determine the percentage of the dissolved nitrogen which constituted the alcohol-precipitable fraction reported as "dissolved protein" in the previous paper.

METHODS

During the season of 1932, five samples were collected and stored in winchester quart bottles, the preservative being 80 grams of ether per litre of liquid. One sample was taken early in the season, the other four towards the end, and these varied in the length of time the pilchards were stored before being put through the reduction process. Details of the samples are given in table I.

The oil was extracted by ether in a continuous liquid extractor, the meal was filtered off, and the filtrate was sterilized by boiling for twenty-minute periods on three successive days. The total nitrogen of every sample under examination was determined before any subsequent analyses were made. A correction for the increased concentration was applied. The necessity of bringing the solution back to its original volume after each period of boiling was thus obvitated.

Total nitrogen content of the samples was determined by the Gunning method, using copper as the catalyst.

Fractional protein analyses were carried out by the method described by Wasteneys and Borsook (1924), modified as follows: all nitrogen compounds precipitable by trichloracetic acid were reported as protein, eliminating the determination of meta-proteins, as distinguished from true proteins; the sub-peptone nitrogen was calculated from the difference between the total nitrogen and that found in the protein, proteose, and peptone fractions.

Total solids were determined by heating 10 millilitres of the effluent in a tared crucible at 98°C. until the residue became constant in weight.

Ash was determined by heating the dried residue in a tared crucible at dull red heat for half an hour, cooling, adding two drops of concentrated nitric acid, reheating, cooling, and weighing. The resultant ash was white and constant in weight, after reheating.

TABLE I. Details of samples collected, with their total solids and ash contents.

Sample	Date collected (1932)	Time of storage of fish before processing	Total solids g./100 ml.	Ash effluent
I	July 15	12 hr.	8.45	1.49
II		6 hr.	8.52	1.56
III	Collected	12 hr.	7.43	1.28
IV	between	30 hr.	7.94	1.29
V	September 1 and 14	36 hr.	8.51	1.20

The nitrogen fraction constituting the "dissolved protein" reported in 1933 was determined by pipetting 25 millilitres of the effluent, with stirring, into 125 millilitres of "methyl hydrate". The precipitate which formed was dried over an air bath at 50°C., weighed and its nitrogen content determined. The alcohol of the filtrate was distilled off, the residue was washed quantitatively into a volumetric flask, made up to volume, and the nitrogen content of aliquots determined.

RESULTS AND DISCUSSION

The total solids and ash content of the samples are given in table I. From this it is seen that while fluctuations occur in these values they cannot be correlated with the time of season or the length of time of storage of the fish before processing. This may be accounted for in part by the fact that the efficiency of the machinery varies with different runs of fish due to variation in their condition, which would influence the composition of the effluent.

The results of the analyses of the alcohol-precipitable solids are given in table II. Three series of analyses were run on a composite sample made up from samples II and III.

From table III it is seen that the protein and proteose fractions of sample II constitute 44.7 per cent of the dissolved nitrogen, while in sample III they constitute 43.7 per cent.

TABLE II. Fractionation of dissolved nitrogen by "methyl hydrate".

Analysis	Ppt. obtained g./100 ml. effluent	N in ppt.	N in filtrate	Total N	Actual N content	% N ppted.	% N in filtrate
		(Nitrogen in mg./100 ml. of effluent)					
A	1.80	259	634	893	892	29	71
B	1.68	244	640	884	892	28	72
C	1.68	245	648	893	892	27	73

In table III interest in the dissolved nitrogenous substances is concerned with their possible economic value as recovered material. Since the amount of dissolved protein is so low, and since it is the only fraction of the soluble nitrogenous substances which could be recovered with any ease, as by the use of precipitants or by the adjustment of the pH of the waste liquors, it is extremely doubtful whether any method of treatment can be devised to recover profitably any of this dissolved matter.

TABLE III. Results of the fractional protein analyses.

Sample	Total N	Protein N	Proteose N	Peptone N	Subpeptone N
		(Nitrogen in mg./100 ml. effluent)			
I	832	28	315	251	238
II	932	58	359	243	272
III	862	68	309	247	238
IV	939	105	338	238	258
V	958	88	301	286	283

Sample	% of N as protein	% of N as proteose	% of N as peptone	% of N as subpeptone
I	3.4	37.8	28.6	30.2
II	6.2	38.5	26.1	29.2
III	7.9	35.8	28.7	27.6
IV	11.2	36.0	25.4	27.4
V	9.2	31.4	29.8	29.6

Apparently from table II the "dissolved protein" of Beall (1933) was made up of the protein nitrogen together with the greater part of the proteose fraction. The analyses indicate, however, that under similar experimental conditions the results obtained are comparable.

The author wishes to acknowledge the co-operation of the Nootka Packing Company, Nootka, B.C., in the collection of material for this study, and the assistance of Dr. J. L. Hart throughout the investigation; and to express his thanks to the Biological Board of Canada for the various facilities afforded.

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